# G.E.C. Journal

VOL. II. MAY, 1931. No. 1.

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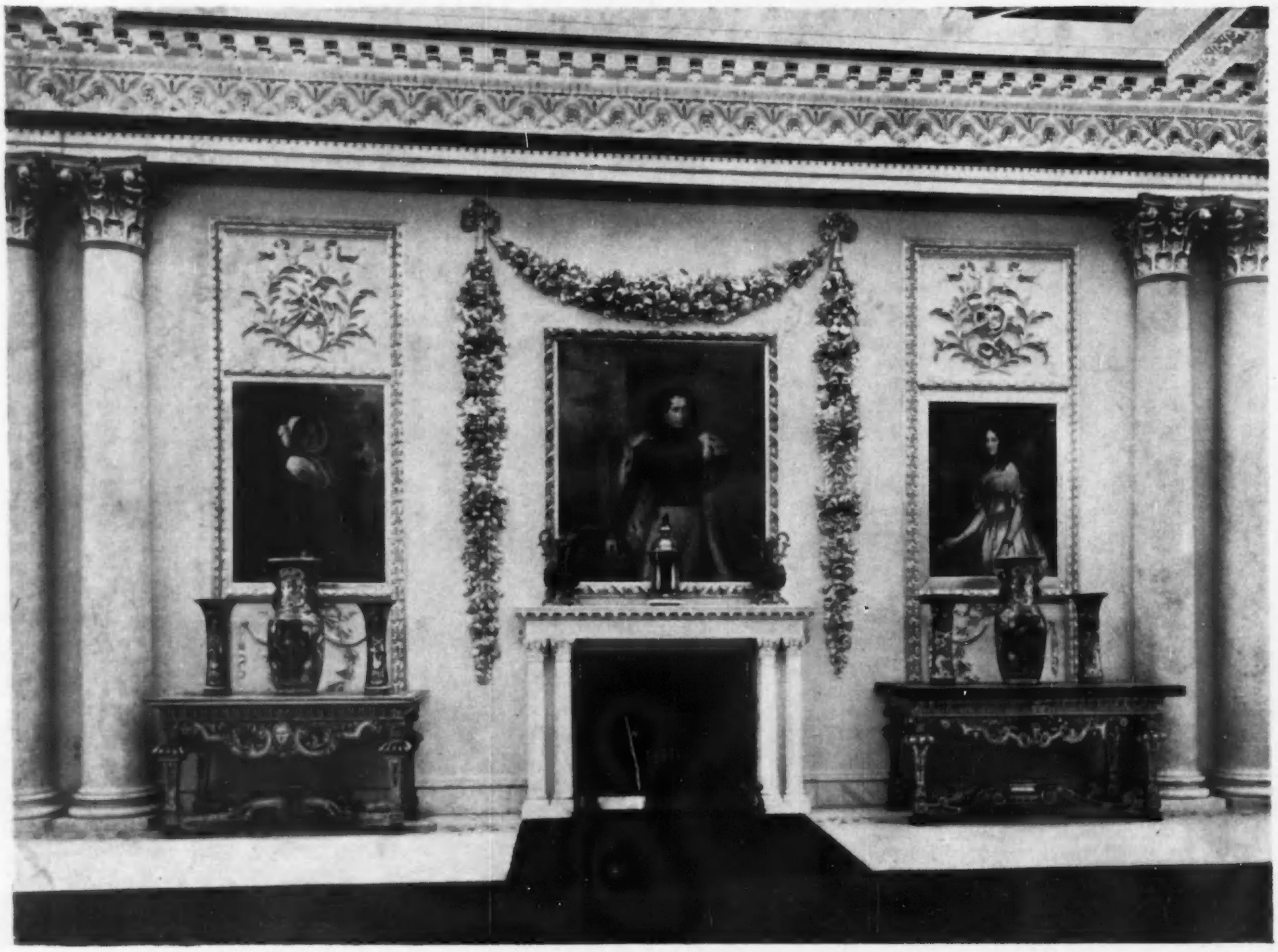
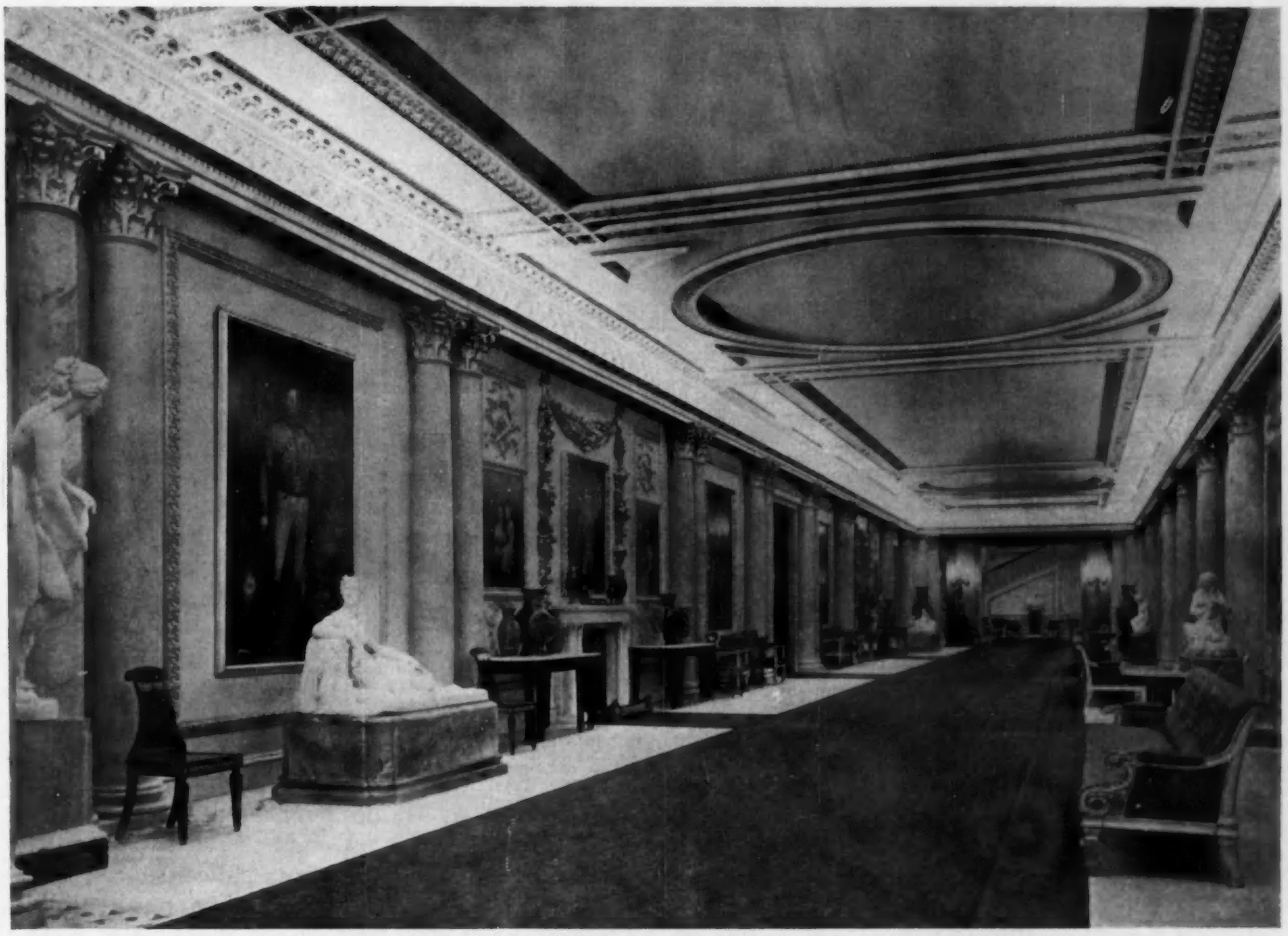
# G.E.C. LIGHTING IN



*The two photographs (reproduced by courtesy of His Majesty's Master of the Household) on this and the succeeding page illustrate one of the most interesting interior lighting schemes ever carried out in this country. Both views are of the Grand Hall, Buckingham Palace, the lighting of which has recently been redesigned by His Majesty's Office of Works, in collaboration with the illuminating engineers of The General Electric Company, Limited.*

*It will be seen that the resultant illumination is of an efficient yet dignified and unobtrusive character, effectively harmonising with the surrounding architecture and mural decorations. . . . . .*

# BUCKINGHAM PALACE



*. . . . The lighting of the Grand Hall is carried out by means of approximately 300 ft. of G.E.C. Striplite reflector of special contour designed to form part of the cornice. 20-watt Osram Striplite lamps form the source of illumination, and are concealed behind the reflector, the exterior of which is finished in gilt.*

*The even illumination obtained is almost entirely free from shadow and forms a particularly effective method of rendering easily visible the many valuable paintings and objects of art arranged along the sides of the Hall.*

*The illustrations are reproduced from straight photographic prints from absolutely untouched negatives taken solely by the artificial light.*

G.E.C. Journal

VOL. II. MAY, 1931. No. 1.

# Discharge Tubes and Their Technical Applications.

## PART I. — HISTORY AND DEVELOPMENT.

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### (1)—HISTORICAL INTRODUCTION.

PHENOMENA accompanying the passage of electricity through gases have been observed and studied far back in history. The lightning flash was a matter for awed bewilderment long before man began to control electrical phenomena for himself, and the miniature sparks and corona discharges of the early static and other "influence" machines were amongst the first manifestations of electrical energy produced by human efforts. The sudden growth of the experimental method amongst scientists and philosophers in the 17th century, together with the corresponding development of fresh tools for their researches, naturally widened the range of phenomena observed. Thus, for example, we find Francis Hauksbee, a contemporary of Newton, experimenting with the air pump and lecturing to the Royal Society in 1709 on "strange effects produced when matter is finely subdivided in vacuo." The electrical discharges produced in his partially evacuated glass vessels when oil or mercury was shaken in them, or directed in jets against their walls, can be set amongst the very earliest demonstrations of their kind.

A big step was taken with the development of the induction coil, a more powerful and more convenient source of high potential electricity than had hitherto been available. The principle of this instrument lay in Faraday's experiments on electromagnetic induction about 1831, but we owe largely to Ruhmkorff the development of the practicable instrument some 20 years later.

Researches conducted with its help form the basis of many of our present day achievements, and workers in this field were numerous. Amongst them the names of Plücker, Geissler, Crookes and Faraday stand out clearly, and have taken a permanent place in scientific nomenclature. Plücker or Geissler tubes are made of plain and fluorescent glasses, shaped into various attractive patterns and with metal electrodes sealed through the walls of the tube. They glow richly when connected to an induction coil, and have long been popular for lecture demonstrations and such like purposes. The names of Crookes and Faraday have been given to two of the dark spaces characteristic of the high voltage, low pressure, gaseous discharge occurring within the tube.

No practical use of discharge tubes was made until Moore began his researches on their value as illuminants in 1893, but it is true to say that such a use had long been foreshadowed, and that Geissler's discharge tubes were, without doubt, amongst the earliest examples of artificial electric light. The first commercial installation of such a lighting system was carried out by Moore, at Newark, New Jersey, U.S.A., in 1904. It consisted of a length of 180 feet of tube, and a high voltage transformer was used

in place of the induction coil. The gas filling in these early installations was usually either carbon dioxide, which gives a whitish light, or nitrogen, which glows with a buff or golden colour. In each case the gas pressure falls as the tube is operated, largely owing to chemical action between the gas and the electrode material, and the light eventually fails unless some replenishing device is adopted. The automatic replenishers devised by Moore constituted his principle contribution to the problem. Moore tubes were installed in the Berlin Palace of Ice in 1910, and in the same year they were introduced into England for lighting offices and works. The whitish light from a carbon dioxide filled tube is a very fair approximation to daylight; such tubes, worked into compact units, were developed in 1912 for colour matching, and find continued use at the present time.

So far only the common gases such as air, hydrogen, nitrogen, carbon dioxide, etc., had been used in discharge tubes, but further developments were made possible by the discovery of the group of inert gases (helium, neon, argon, krypton and xenon) by Rayleigh, and Ramsay and Travers. These gases are prepared by the fractional distillation of air. Helium is also obtained from certain minerals and from some natural gases.

The necessity for the automatic replenishing devices, to overcome the gradual disappearance of the gas filling in Moore tubes, was avoided by the use of these rare gases, which do not "clean-up" readily in this way. In particular, neon was used. Tubes filled with this gas at a low pressure had been employed by Fleming as sensitive detectors of electrical oscillations, and as a convenient method of measuring their wavelength. In 1910, Claude introduced large tubes, filled with neon, for display purposes. Their attractive red colour and higher luminous efficiency made them suitable for advertising purposes, and a further development lay at hand, in the use of mercury as an addition to the rare gas, which gave a bright blue colour to the discharge.

Tubes of a different type containing mercury and its vapour alone, were developed by Arons in Germany and Cooper Hewitt in America, and with suitable striking gear could be made to operate from comparatively low voltages. The luminous efficiency was high, but the light was completely lacking in red rays. Nevertheless, they have found many special uses, such as for studio lighting. Numerous attempts were made to improve the colour of the light emitted, and Wolke produced in 1912 an arc discharge lamp, containing cadmium and mercury, which was more satisfactory, but did not come into widespread use.

The most recent development is the hot cathode discharge lamp which allows a high intensity discharge tube to operate direct from the normal low voltage electrical supplies. Neon tubes of this type, for use as air beacons, were made in America in 1928, and work on similar lines has progressed in England and Germany where a wide range of such lamps, both gas and vapour-filled, has been produced.

*In Part* I. *of this article an historical account of the development of discharge tubes and of their relationship to modern theories of atomic processes is given, together with a brief outline of phenomena occurring within the discharge between cold electrodes. Part* II. *gives a more detailed theoretical description of the discharge.*

*Part* III. *will deal with practical applications of discharge tubes and methods of manufacture, with special reference to important developments which have recently been made.*

### (2)—THE CONDUCTION OF ELECTRICITY THROUGH GASES.

There are striking and fundamental differences between the passage of an electric current along a metallic or carbon conductor, and the flow of current between the electrodes of a discharge tube. In the former case no matter how small is the potential applied, a steady current flows, and a uniform potential gradient is established. In the latter case, comparatively large potentials may produce currents which can be detected with only the most sensitive of instruments, but a small increase of voltage may result in the sudden flow of large currents, accompanied by beautiful and fascinating glows and streamers within the tube. Furthermore, there is a strict proportionality in the first case between the applied potential and the current produced, and this ratio measures the electrical resistance of the conductor, but no such constant can be determined for the "resistance" of the gas. When very small currents only are flowing, this latter will appear to offer a very high resistance to the passage of electricity, but as the current increases the apparent resistance falls, and, unless stabilization is effected in the external circuit, very large currents will flow, accompanied by vivid discharges and the eventual fusing of the electrodes. Furthermore, the potential gradient along the tube is far from uniform.

The understanding of discharge tube phenomena has been closely linked with the development of modern theories of the ultimate structure of matter. Whilst little explanation of the one can be given without appeal to the other, it is equally true that much of the advance in our knowledge of atomic processes has been made in the course of the study of the electric discharge.

In the fruitful years of the latter half of the 19th century, a conception of the atomicity of electricity arose and took its place with earlier and long discussed theories of the atomicity of matter. The

recognition that material atoms were made up of positive and negative units of electricity, and the identification of the negative unit with the atom of electricity, or electron, was largely due to work on discharge tubes carried out by Sir J. J. Thompson and his collaborators in the Cavendish Laboratory.

In a comparatively few years, simple pictures of atomic structure have given place to theories of the utmost complexity, but all of them are based on the same fundamental idea. The atom is considered as made up of a central massive and positively charged nucleus, associated with a group of negative charges, or electrons, whose energies and spatial dispositions are definite in the normal atom.

Recent discoveries of the wave nature of the electrical units, regarded hitherto as particles, have modified the earlier picture of the atom as a simple planetary system, but the underlying principles remain much as before. Energy can be absorbed by the normal atom only in discrete quantities, or "quanta," of energy, resulting in the transference of

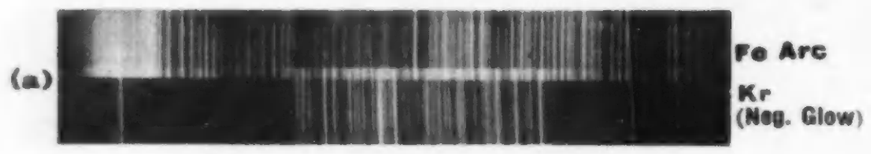


**Fig. 1.—(a) Line Spectrum (Krypton).**
**(b) Band Spectrum (Carbon Monoxide).**

an electron from its normal position, or energy level, to one of higher energy, farther from the nucleus. The atom is then said to be in an excited state. The energy thus absorbed can be emitted again, but once more only in discrete quantities associated with the return of the electron through the various permissible energy levels towards its original orbit. The energy thus released is emitted as electro-magnetic radiation of a definite frequency. If an electron falls from a level associated with energy $E_2$ to another associated with energy $E_1$, the frequency $\nu$ of the radiation emitted during the transition is given by

$$E_2 - E_1 = h\nu \qquad (1)$$

where $h$ is Planck's universal constant ($6.56 \times 10^{-27}$ erg seconds).

The atoms of a given element all have the same system of energy levels, characteristic of that element. Not all the possible theoretical transitions of electrons between these levels take place in reality, since experimental evidence shows that certain selection rules govern the energy transferences. Furthermore, under certain conditions, particular transitions are greatly favoured. The radiations accompanying those transitions which do occur make up the spectrum characteristic of the element in question. Radiation occurring in that region of the complete spectrum to which the eye is sensitive, constitutes the coloured glow which we see when a discharge tube is in operation.

So far we have considered the line spectra which are characteristic of atoms, but similar ideas may be applied to molecules, whose spectra frequently consist of bands composed of numbers of lines grouped closely together. The simplest case is that of a diatomic molecule such as nitrogen where the model of the molecule may be regarded as a dumb-bell the heads of which are the two atoms. The orbital electrons of each atom may be regarded as arranged around the dumb-bell shaped nucleus. The system may have energy of rotation about its centre of gravity, and the individual atoms may vibrate along the axis joining them.

The permissible rotational and vibrational energy changes are restricted by quantum conditions just as the electronic transitions are.

Changes in the rotational and vibrational energies alone, result in the emission of groups of lines in the infra-red region. If electronic transitions take place along with the rotational and vibrational energy jumps, the bands usually occur in the visible or the ultra-violet regions of the spectrum. Photographs of typical line and band spectra are shown in fig. 1.

The simplest process by which an atom or molecule is raised to an excited state is through electronic impact. An electron moving in an electric field acquires energy of motion $E$, given by

$$E = e\,V \qquad (2)$$

where $e$ is the charge on the electron and $V$ the voltage through which it has fallen. Its energy is then said to be $V$ electron volts. On colliding with a neutral atom it rebounds without loss of energy unless

$$E \geqq h\,\nu_c \qquad (3)$$

where $\nu_c$ is the frequency corresponding to the least energy transference permissible within the atom by quantum condition (1). Providing then that the colliding electron has sufficient energy, it will raise an electron within the atom from its normal energy level to one of the other permissible higher levels, and may even eject an electron from the atom, which is left positively charged, and is known as a positive ion. In every case the atom absorbs energy in definite amounts, and the colliding electron rebounds with the balance of energy, if any. It is usual to refer to the energies of these levels in the atom, in terms of electron volts, the lowest of these

energies being the first resonance potential. The energy required to remove the electron from the atom is referred to as the Ionisation Potential. A table of these potentials for some common elements is given below.

Table 1.

**EXCITATION AND IONISATION POTENTIALS OF SOME COMMON ELEMENTS.**

| Element | 1st Resonance Potential Volts. | Ionisation Potential Volts. |
|---|---|---|
| H | 11.1 ($H_2$) | 13.59 |
| N | 7.9 ($N_2$) | 14.50 |
| P | — | 10.5 |
| O | 6.1 ($O_2$) | 13.56 |
| S | — | 10.31 |
| C | 5.0 | 11.22 |
| He | 19.4 | 24.48 |
| Ne | 16.6 | 21.47 |
| A | 11.6 | 15.69 |
| Kr | 9.9 | 13.9 |
| Xe | 8.3 | 12.1 |
| Li | 1.8 | 5.36 |
| Na | 2.1 | 5.11 |
| K | 1.6 | 4.33 |
| Rb | 1.5 | 4.13 |
| Cs | 1.4 | 3.86 |
| Cu | 3.8 | 7.69 |
| Mg | 2.7 | 7.61 |
| Ca | 1.9 | 6.09 |
| Sr | 1.8 | 5.65 |
| Ba | 1.6 | 5.19 |
| Zn | 4.0 | 9.36 |
| Cd | 3.8 | 8.95 |
| Hg | 4.9 | 10.39 |

Excitation and ionisation are also possible following the impact of positive ions on atoms, but the efficiency of such collisions is much smaller than that of collisions between electrons and atoms. Just as the fall of an electron from one energy level to another of lower energy content is accompanied by the emission of radiation, so the reverse transition may take place by the absorption of the same radiation. This is known as photo-excitation. A well known example of this is the excitation of sodium vapour when illuminated by the yellow "D" lines, the quantum energy of which is 2.1 electron-volts. Cumulative ionisation by the successive impacts of electrons and atoms, or by direct transfer of energy from excited atoms to others, may also occur.

It is now recognised that there are in some atoms certain excited states or energy levels from which the electron cannot depart, with the emission of the excitation energy as radiation, in the usual manner. The only way in which an electron in a metastable state—as these excited states are called—can return direct to the normal state, is by transferring its energy to another atom in an inelastic collision. Atoms cannot be raised to stationary states of this kind by the absorption of radiation corresponding to the energy difference between the metastable and the normal states. Mercury has a well known metastable state at 4.68 electron volts. This state has been determined with great precision by Franck and Einsporn. No radiation corresponding to this energy is known in the mercury spectrum.

The life of a metastable atom depends on the pressure of the gas, the size of the containing vessel and the presence or absence of other atoms. Thus the average life of a metastable mercury atom at a pressure of 0.001 mm. is of the order of $10^{-3}$ seconds. The average life of an ordinary excited atom is of the order of $10^{-8}$ seconds.

**(3)—THE MECHANISM OF THE DISCHARGE.**

It is now possible to outline a preliminary simple picture of the processes occurring when a high potential is applied to the electrodes of a discharge tube, and the tube is seen to strike. It is necessary to explain how current passes through the gas and why visible radiation occurs. There are always a few electrons and ions in the gas. In a closed vessel, for example, it is an experimental fact that some are constantly being produced, and therefore that the gas has always a small, but finite conductivity. There is no doubt that this ionisation is due partly to minute traces of radioactive materials which are present everywhere, and partly to ionisation by the highly penetrating cosmic radiation. The latter alone produces at sea level one or two ions per cc. per second, and a total of some 10—15 ions per cc. may be produced in the vessel each second by external agents.

On the application of the high voltage to a discharge tube, an approximately uniform field is set up between the electrodes. Under its influence the positive ions move towards the cathode and the electrons toward the anode, acquiring increasing velocity and energy as they do so. If the field is large enough, this energy soon becomes sufficient for further ions and electrons to be formed by collisions between electrons and atoms, the process being a rapidly cumulative one. Furthermore, the cathode itself becomes a source of electrons emitted under positive ion bombardment and photoelectric action. The movement of ions and electrons to the electrodes constitutes an electric current, which grows rapidly to a value limited by external circuit conditions. At the same time a visible discharge is established as excitation and radiation processes occur amongst the atoms within the discharge. The electric field along the tube now ceases to be linear and becomes largely localised near the cathode, where an accumulation of positive ions produces a positive space charge, an effect akin to that met with in thermionic valves, where it is due to an accumulation of electrons near the filament.

**(4)—DESCRIPTION OF THE GLOW IN RAREFIED GAS.**

A description of the phenomena which are seen in a discharge tube during exhaustion when a high potential is applied to the electrodes, must be given for the sake of completeness.

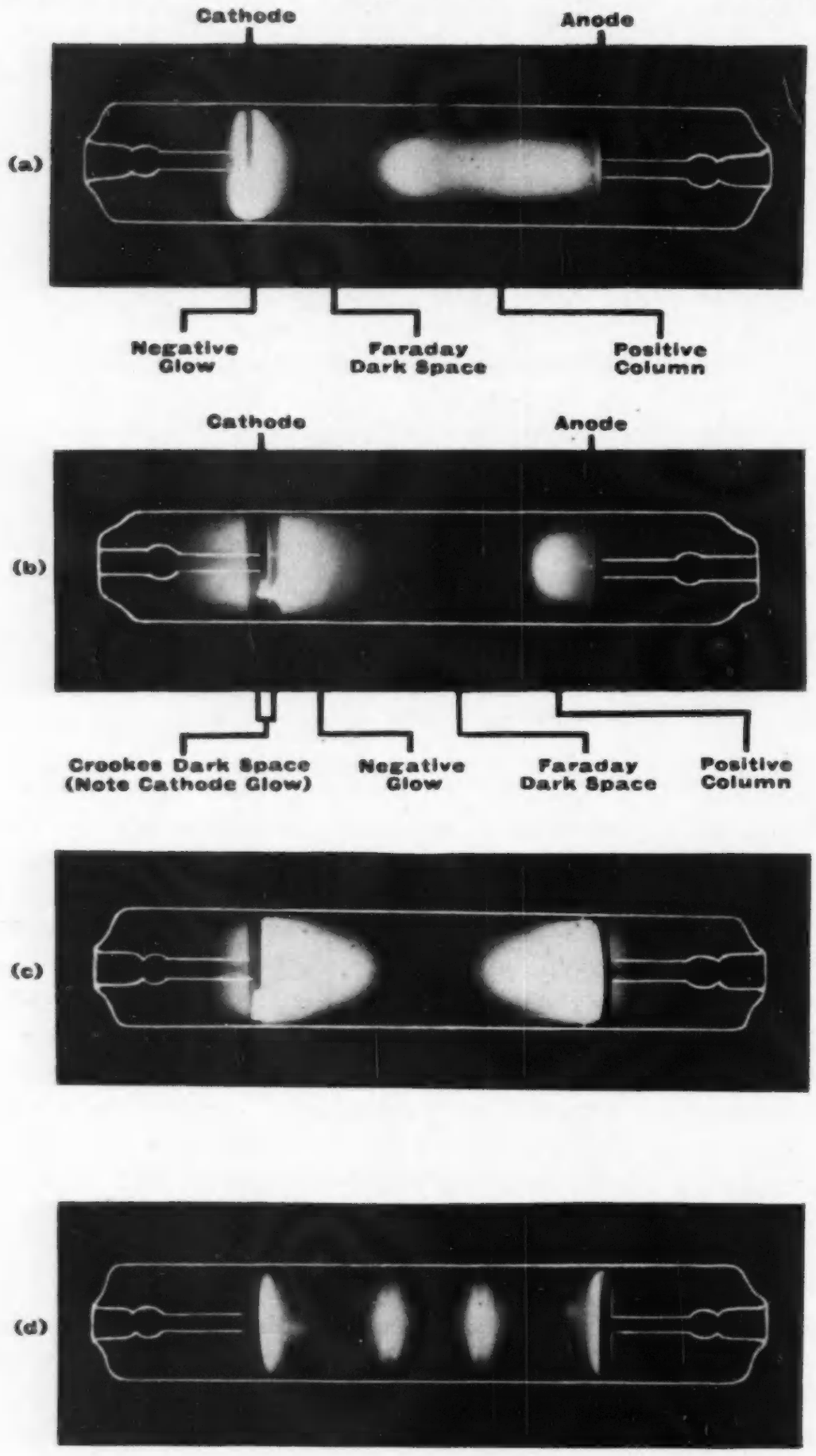
The discharge in a gas at pressures of the order of an atmosphere does not concern us greatly here. It takes the form of a rapid stream of sparks which tends to spread out at the cathode. As the pressure of the gas is lowered, the discharge assumes a cord-like appearance waving from side to side in the tube, and at pressures of the order of a centimetre or two of mercury this cord-like discharge has expanded until it almost fills the tube.

The fully developed discharge through a gas rarefied to the proper degree presents to the eye the most astounding changes of colour and form.

The most striking divisions in the discharge, when developed in this manner, are five in number. Proceeding from the cathode towards the anode there is the glow which covers the cathode itself, generally of a different colour from the rest of the discharge. This is known as the cathode glow.

Following this, there is a relatively dark space the extent of which depends on the gas pressure. As will be described later, it grows larger as the pressure is lowered. This dark space, which is known as the Crookes or cathode dark space, can be detected in most gases at pressures of the order of a few millimetres of mercury.

The Crookes dark space is bounded on the anode side by another glow which at low gas pressures becomes a cloud of light. This is called the negative




(a) Direct current discharge in neon.

(b) Direct current discharge at lower pressure showing Crooke's dark space and cathode glow.

(c) Alternating current discharge showing overlapping Faraday dark spaces.

(d) Alternating current discharge showing striations.

**Fig. 2.—Reproduction from actual photographs of a simple tube operating on both D.C. and A.C. The tube outlines have been drawn in.**

glow. Considerable technical use is made of this part of the discharge. Following this glow is the Faraday dark space, which is often as great as a hundred times the width of the Crookes dark space, referred to previously. The positive column, which is usually the most interesting and conspicuous part of the discharge, lies between the Faraday dark space and the coloured flecks of light on the anode. Its extent depends largely on the pressure of the gas, and at pressures of the order of a few millimetres of mercury, it is the chief region of luminosity in the tube.

It is the positive column which is made use of in "neon" sign work, and it has other important applications, which will be described later.

Some of the remarkable effects which, under certain conditions, show themselves in this part of the discharge, may conveniently be described here. If the gas in the tube is contaminated with a trace of impurity in the form of another gas, the positive column frequently splits up into a regular row of coloured balls or discs of light. These striations, as they are called, assume in certain circumstances the most incredible diversity of form and colour.

Thus in a tube filled with neon to about 10 millimetres pressure, most beautiful effects can be obtained when the tube is excited by alternating current and the impurity is a trace of certain organic vapours.

Sometimes the striations take the form of multi-coloured serrated discs which are frequently seen to rotate round the axis of the tube. If the concentration of impurity is changing, as it generally will be owing to the removal of the vapour by the action of the discharge, the striations progress along the tube towards one or other of the electrodes. Usually this type of discharge becomes unstable after a time, or it can be made unstable by changing (usually increasing) the current through the tube. The discs are seen to break up and the positive column assumes the form of a number of narrow cords of light which move about within the tube in an irregular and fascinating manner. This animated positive column type of discharge was hitherto known only as a very transient effect obtained usually while the tube was being pumped. It is quite different from the waving positive column obtained at pressures near atmospheric. It has been developed at the Research Laboratories of the General Electric Company Limited, for application to "neon" sign work, and applications have been made for patents covering methods for maintaining these effects. It is known commercially as "Ripple Neon" and it will be described later in some detail.

To complete our survey of the parts of the discharge we will only mention the Aston, or Primary, dark space which occurs in some gases. It lies between the cathode and the cathode glow, and in the case of helium, which is one of the few gases that show it well, the primary dark space may be seen as a very thin dark line.

The appearance of a discharge excited by alternating current is usually quite different from that presented by the direct current discharge.

To a first order of approximation the state of affairs inside the tube excited by A.C. of ordinary commercial frequencies is the same as when a steady D.C. is exciting it, except that the anode and cathode interchange each half cycle, the various parts of discharge changing their positions in the tube with the change in polarity. Since the applied potential goes through zero once each half cycle the discharge must go out and restrike in the next half cycle.

Owing to persistence of vision the eye, of course, sees both half cycles superposed, and the discharge presents a symmetrical appearance in the tube. The negative glow appears at both electrodes and the positive column starts out from each of them.

Figs. 2 (a), (b), (c) and (d), show reproductions from actual photographs of a simple tube operating on both direct and alternating currents.

## PART II. — THEORETICAL CONSIDERATIONS.

It is true to say that there is to-day a fairly complete understanding of all but the most complicated processes occurring within the discharge, but only a brief outline of the theory of the phenomena described in Section 4 falls within the scope of this article. The overall behaviour of the tube will be considered first of all, and then each characteristic portion of the discharge will be dealt with in turn.

### (5)—THE SPARKING OR STRIKING POTENTIAL.

A brief account of the phenomena taking place during the striking of a discharge tube has already been given in Section 3.

The exact mechanism of the initiation of the discharge is still a controversial matter, but there is little doubt that the process described is substantially correct. Imagine one electron to move from cathode to anode under the influence of the field, and to ionise by collision $n$ atoms on its journey, forming $n$ electrons and $n$ positive ions. Suppose all these latter to strike the cathode, thus liberating $nm$ further electrons, $m$ being an efficiency factor less than unity. A self-maintained discharge can be established if the product $nm$ is greater than unity. Experiment indicates that $n$ depends on the applied potential $V_A$, the gas pressure $p$, and the geometry of the tube, but that $m$ is substantially independent of these, although it may vary for different cathode

materials. Both $n$ and $m$ vary with different gas fillings. The striking potential $V_S$ is then given by some such expression as

$$f(V_S, p) = \frac{1}{m} \qquad (4)$$

and the curve connecting $V_S$ and $p$ is of this form :

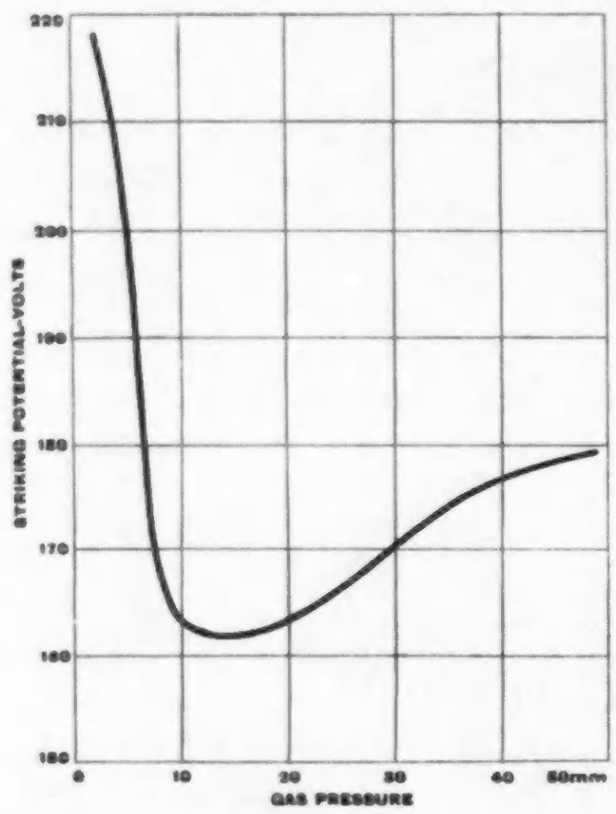



**Fig. 3.—Curve showing variation of striking potential with gas pressure in a discharge tube used as an over-voltage protective device. Gas : 80% neon-helium mixture. Electrodes : Nickel discs, 3 mm. apart.**

In a tube with an electrode system of simple geometry, such as parallel plates, if the distance apart, $l$, of these be varied, and $p$ adjusted to make $V_S$ a minimum for each value of $l$, it is found that

$$pl = k \qquad (5)$$

where $k$ is a constant. This is to say, the striking potential depends only on the volume of gas between the electrodes. This is known as Paschen's Law. If $l$ is less than $\frac{k}{p}$ the discharge may take the longer path to the back of the electrode.

Although a discharge tube will never strike with applied potentials less than $V_S$, when the applied potential $V_A$ is very near to $V_S$, the discharge may occur only after an appreciable time lag. The cause of this lag is not fully explained, but films of gaseous impurities adsorbed on the cathode surface, and removed by positive ion bombardment during the initial stages of the discharge, may play an important part. The greater $V_A$ is in excess of $V_S$, the smaller is the lag, which may vary from about $10^{-6}$ to $10^{3}$ seconds. Any external agent promoting ionisation within the tube, *e.g.*, a speck of radioactive material, reduces the lag, or even the striking voltage, considerably. Certain tubes which are particularly sensitive in this respect, have been used to detect mislaid radium needles. The striking potential is very sensitive to traces of impurity in the gas filling or on the electrodes. For example, in a particular discharge tube with parallel plate electrodes, 0.0011 per cent. of pure argon, added to pure neon, reduced the striking potential from 512 volts to 334 volts. This large reduction can be explained in the following way. The ionisation potential of neon is 21.5 volts, and ionisation of the gas will not generally take place unless electrons with this energy are available. However, the resonance potential of neon (16.6 volts) is higher than the ionisation potential of argon (15.7 volts), and therefore neon atoms excited by electrons of energy less than the ionising potential of neon, in particular metastable atoms of neon, are able to ionise the argon and thus assist in initiating the discharge. Hydrogen and mercury may also be used in this way, but are not so effective as argon. A curve showing the effect of the addition of small quantities of hydrogen to the neon-helium filling of the 200 volt Osglim type of small discharge lamp is given below.

The liberation of electrons at the cathode surface by positive ions is closely linked with the energy required to move an electron through the surface of the cathode, *i.e.*, with the thermionic work function ($\phi_e$) of the electrode material. This itself depends greatly on the surface cleanliness, and films of impurities, whether partial or complete, may alter $\phi_e$ considerably. Electro-negative elements, such as oxygen, raise it, and electro-positive elements,

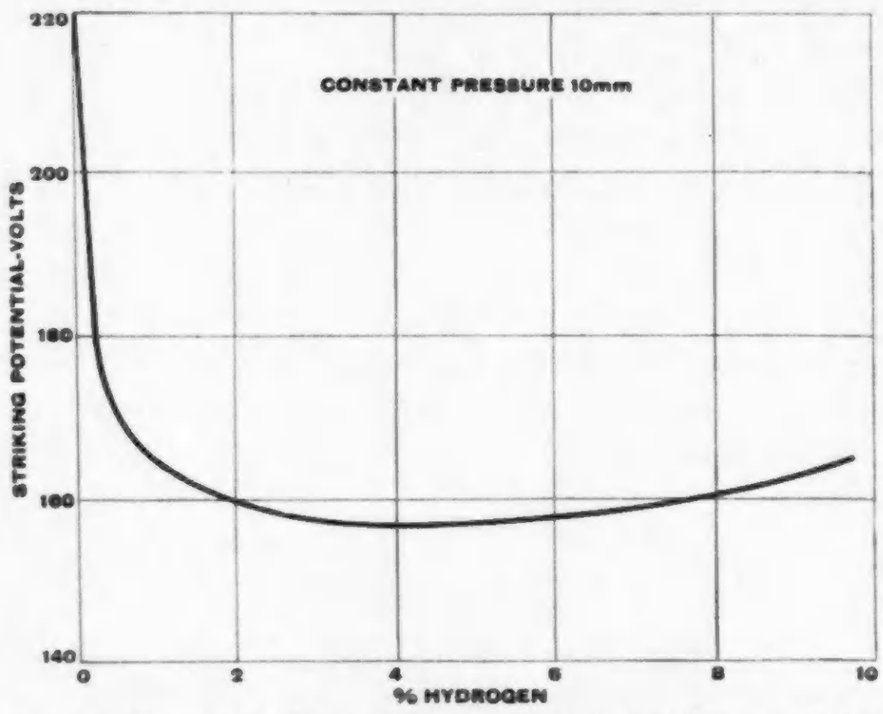



**Fig. 4.—Curve showing the variation of striking potential in an Osglim lamp with the addition of hydrogen to the 80% Neon-Helium gas filling.**

such as sodium, reduce it very greatly. In this way, the factor $m$ may be reduced or increased, and $V_S$ changes accordingly.

For small tubes with cold electrodes close together and filled with neon, helium or argon, $V_S$ lies between about 150 and 250 volts. For krypton and xenon, and the common gases such as nitrogen or carbon dioxide, it is about 100 volts higher. In the tubes some metres in length employed for display purposes, $V_S$ may rise to some 10,000 volts,

and in small tubes with electrodes specially sensitised with the alkali or alkaline earth metals, it may be as low as 70 volts, or even less.

On sinusoidal A.C. circuits, the R.M.S. voltage at which the tube strikes is approximately 0.7 times the D.C. striking potential. The striking potential during the subsequent half cycles is generally less than this, probably owing to some of the ions persisting during the "out" period.

### (6)—THE CURRENT-VOLTAGE CHARACTERISTIC.

The complete characteristic for a small discharge tube fitted with cold electrodes and filled with neon at about 1 cm. pressure is shown in fig. 5. As the voltage, applied through a high series resistance, is increased, no appreciable current passes until the striking potential $V_S$ is reached. At this point a faint luminosity appears near the anode, and a very small current flows. If the series resistance is reduced, the portion *ab* of the characteristic is followed, the faint luminosity meanwhile increasing, spreading towards the cathode, and possibly breaking up into striations. At *b* the glow is only a few millimetres from the cathode, and separated from it by the fairly well defined Crookes dark space. Further decrease of series resistance is accompanied by a spread of the glow over the surface of the cathode, whilst the voltage across the tube no longer falls with increasing current, but remains approximately constant until the glow covers the entire surface of

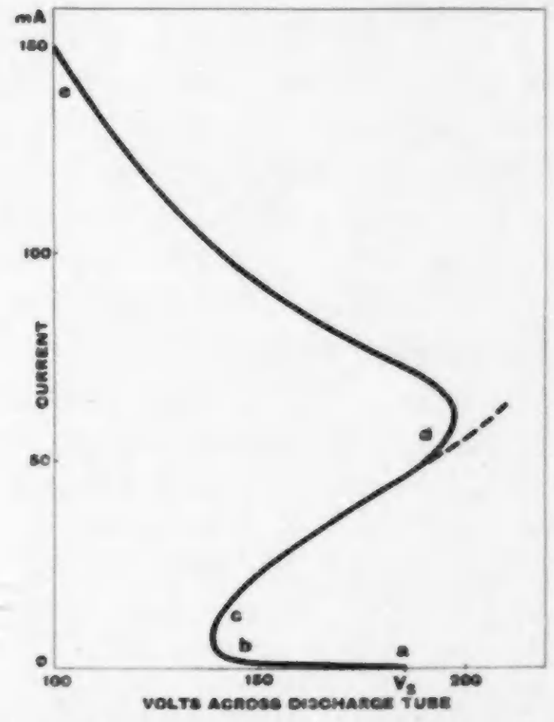



**Fig. 5.—The complete characteristic of a cold cathode discharge tube.**

the cathode (*bc*). This corresponds to the conditions of "normal" cathode fall of potential, the current density over the glowing portion remaining approximately constant at about 0.1 mA per sq. cm. As the series resistance is decreased still further, the voltage across the tube increases with increasing current due to an increased potential, the "abnormal" cathode fall, across the Crookes dark space. At the same time this dark space contracts (*cd*). Currents of the order of 0.1 amperes per sq. cm. of cathode may be passing, and in consequence the cathode will become hot and will finally act as a source of electrons by thermionic emission. The discharge now passes into the arc stage, with a negative characteristic (*de*) and currents of several amperes per sq. cm. will flow, limited only by the value of the series resistance.

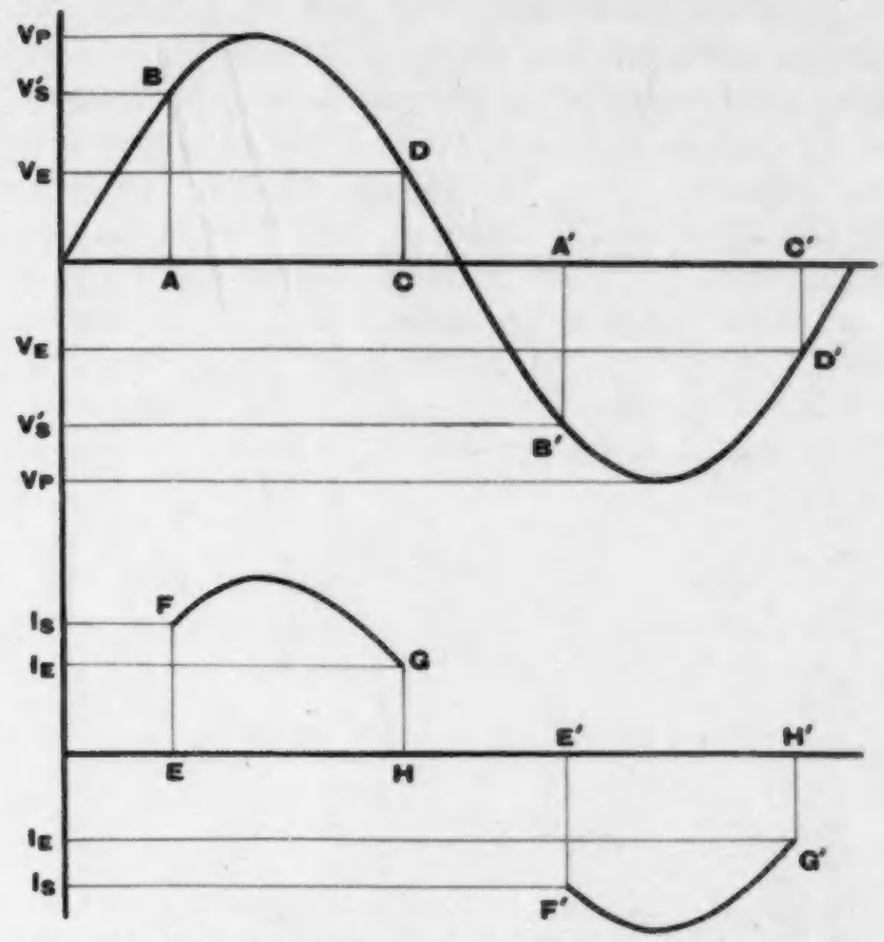



**Fig. 6.—Behaviour of a discharge tube on A.C. circuits.**

Unless the electrodes are specially designed for the purpose, they will rapidly fuse under this treatment, and the tube will be destroyed. The characteristic obtained when a hot cathode, deliberately designed to act as a source of electrons by thermionic emission, is employed, will be given in a later section of the article when hot cathode tubes are discussed fully.

When a sinusoidal alternating potential is applied to the electrodes of a tube through a stabilising resistance, the discharge will pass and reverse each half cycle, providing the peak voltage, $V_P$, of the A.C. supply exceeds the D.C. striking voltage, $V_S$, of the tube. We shall assume that the frequency of the alternating current is within the limits of ordinary commercial supplies, *i.e.*, between 25 and 100 cycles per second.

In fig. 6 the upper curve represents the sinusoidal potential applied to the tube, with a horizontal time axis. If $AB = V'_S$, the striking potential of the tube during each half cycle, and $CD = V_E$, the extinguishing potential, then the potential across the tube rises to $V'_S$, where the tube strikes. The current suddenly rises to a value $I_S$ (*EF*) corresponding to $V'_S$. It follows the path of the curve *FG*, to a value $I_E$ and suddenly falls to zero (*GH*) when the applied potential has fallen to $V_E$, the extinguishing value. The tube remains out until the point $B'$ is reached when the sequence is

repeated, with the current passing through the tube in the opposite direction.

If one electrode is very small compared with the other, which we will suppose is working inside the range of the normal cathode fall, then the mean volts across the tube during the two half cycles may not be the same. This will be the case if the cathode fall is abnormal during those half cycles when the smaller electrode is cathode. In consequence the tube current alternates between a high and a low value each half cycle. This fact is of importance in connection with the theory of the action of certain types of gas rectifiers, which work on this principle. The tube may, of course, be working outside the range of the normal cathode fall during both half cycles, but a rectifying action may still result. This may be seen from the approximate

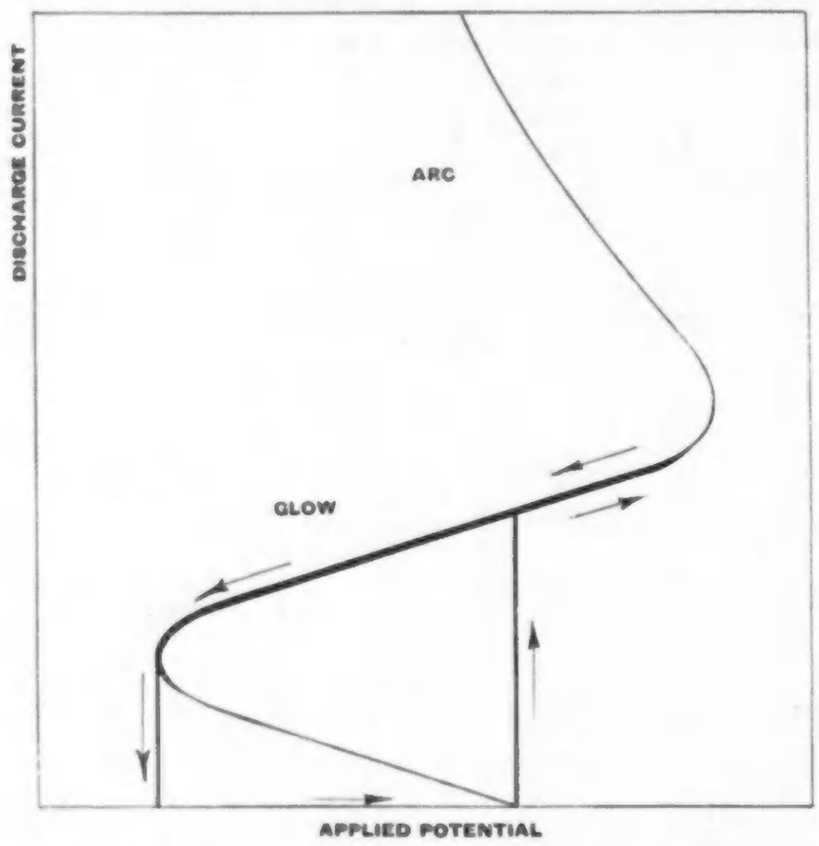



**Fig. 7.—Hysteresis in discharge tubes.**

relation following, which applies to abnormal cathode fall conditions.

$$I = \frac{E - e}{\frac{I}{AM} + R} \qquad (6)$$

where $I$ is the current through the tube in amperes.
$E$ is the R.M.S. voltage of the supply.
$R$ the value of the series resistance.
$A$ the area of the cathode in cms$^2$., and
$e$, $M$ constants of the gas, and the form and material of the electrodes.

It follows at once from (6) that smaller current goes along with smaller cathode area.

### (7)—HYSTERESIS EFFECTS AND OSCILLATION.

From fig. 5 it is clear that the discharge may be maintained at voltages well below the striking potential, and that if the applied voltage is varied between definite limits, the particular portion of the characteristic traversed will vary with varying circuit conditions, whilst discontinuities may occur in passing from one branch to another. Fig. 7 illustrates this point.

Frequent use is made of the circuit illustrated in fig. 8, or modifications of it, to employ a discharge tube as an oscillation generator, the periodic charging of the condenser $C$ and its subsequent discharge through the tube, being a simple means of traversing regularly the hysteresis loop shown in fig. 7. If the time of discharging is small compared with that of charging, and if lag in the striking of the discharge is neglected, the period $T$ of the oscillations produced is given by

$$T = CR \log_e (V_A - V_E) \,/\, (V_A - V_S) \qquad (7)$$

where $C$ and $R$ are respectively the capacity and resistance in circuit, $V_A$ is the applied potential, and $V_S$ and $V_E$ are respectively the striking and extinguishing potentials of the tube. $T$ may vary from many seconds to a very small fraction of a second corresponding to a high audible frequency, and the wave form produced is rich in harmonics. Unfortunately the constants $V_S$ and $V_E$ for any tube are liable to show progressive change and

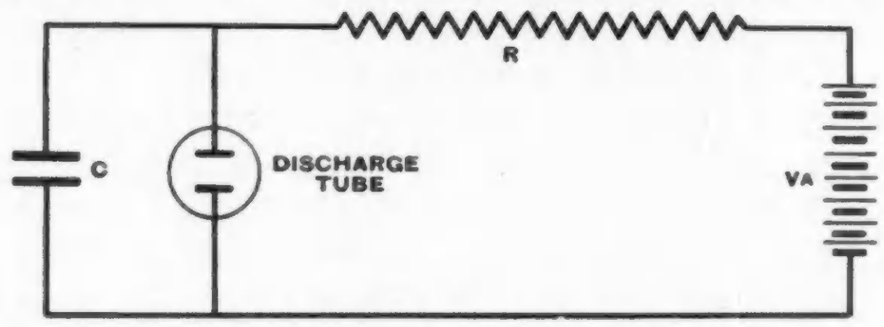



**Fig. 8.—Discharge tube oscillator circuit.**

erratic fluctuation, and in consequence this type of oscillator proves in practice to be unreliable.

In addition to these artificially produced oscillations, discharge tubes are liable to generate self-oscillations of audio or radio frequencies which are unaffected by changes in the resistance, inductance or capacity of the external circuit. They are frequently associated with the anode glow and are usually referred to as "ionic oscillations," since their origin is in the ions and electrons within the tube.

### (8)—EXPERIMENTAL ANALYSIS OF CONDITIONS WITHIN THE DISCHARGE.

There is no direct method of studying the distribution of potential and of electric field within the discharge, and indirect methods have to be adopted, care being taken that the discharge itself is unaffected by the particular means employed. Early attempts to determine the field within the cathode dark space were made by shooting a beam of electrons through successive points in this region of the discharge, and determining the deflections of the beam that were produced at each place, from which the fields at the various points could be determined. A second method which has found considerable use depends on the sub-division of a spectral line into

various components, which occurs when the source is placed in a strong electric field. This is the Stark effect, and the field within the dark space when the cathode fall is high is sufficient to influence the atoms radiating within the dark space in precisely this way. An image of the discharge from the cathode to the negative glow is thrown on to the slit of the spectrograph, and the Stark effect shows in the spectrum photograph as a patterned displacement of the normally straight spectral lines, from which the electric field strengths throughout the dark space can be determined. This is a valuable method since no disturbance of the discharge itself need take place.

Attempts to measure the distribution of potential throughout the tube were first made by the insertion of small probe electrodes (usually fine wires) whose potentials relative to one or other of the electrodes could be determined with an electrometer. Each probe was imagined to take up the potential of the discharge surrounding it, but a little consideration showed that this is not the case. If the insulated probe is to remain in equilibrium with the discharge, equal numbers of electrons and positive ions must be collected by it, and on account of the higher mobility of the electrons, an excess of these is usually received unless the probe takes up a potential negative to the discharge. Furthermore, the introduction of the collector is very likely to disturb the conditions of the discharge.

This may be overcome to a large extent by the use of a sufficiently small probe, and the other disability can be avoided by measuring the current versus voltage characteristic for the collector as its potential with respect to either the cathode or the anode is varied. At high negative potentials only positive ions are collected, but at lower potentials, electrons with high velocities reach the collector against the field. As the space potential is approached an increasing number of electrons is received, and as the space potential is passed they are collected in an accelerating instead of a retarding field. Analysis allows of separation of the positive ion and electron currents, and if a characteristic is drawn showing the logarithm of the latter against the collecting voltage, the space potential is indicated by a change of slope, as shown in fig. 9.

From the fact that the characteristic in the retarding field is rectilinear it may be deduced that the electrons have a Maxwellian distribution of velocities, and their effective "temperature" is calculable from the slope of the line. From the current at the space potential and the dimensions of the collector, the concentration of electrons within the discharge may be determined, and similar information can be obtained about the positive ions. It is obvious that this is a very powerful method of investigating gaseous discharges. It was developed by Langmuir and Mott-Smith in America, and first applied by them to mercury vapour arcs. Collectors in the form of plates, small spheres, or fine wire cylinders were used.

Determination of the space potential can also be made by the use of a small filament. When hot, this filament will emit electrons, but can only do so if it is at a negative potential with respect to the discharge. If then its potential is raised until no change in the net current to it is observed when it is made hot or cold, its potential must be that of the discharge at this point.

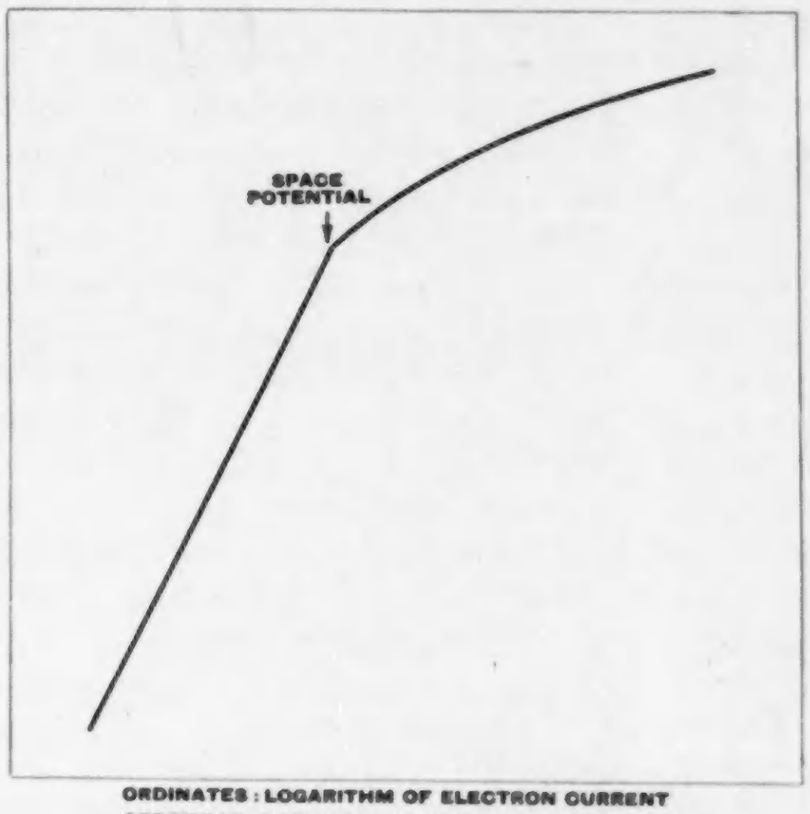



Fig. 9.—Collector characteristic.

### (9)—CATHODE PHENOMENA.

Theories of the phenomena occurring at or near the cathode are not completely satisfactory. We have seen how, in the self-maintained discharge, the cathode appears to act as a source of electrons, which move across the Crookes dark space under the action of the field. It seems most probable that these electrons are largely produced by bombardment of the cathode with positive ions, although photoelectric emission due to radiation from other parts of the discharge may play its part as well. The electrons in their passage across the Crookes dark space collide with atoms of the gas and produce fresh ions and electrons. Further ionisation in the dark space may take place from radiation. The highly mobile electrons move towards the negative glow whilst the slower positive ions drift towards the cathode, setting up a positive space charge. It is this region of positive space charge which constitutes the cathode dark space, and the electric field within it falls rapidly with the distance, from a maximum at the cathode to zero at the edge of the negative glow.

The Primary, or Aston dark space has already

been mentioned. For "normal" discharge conditions it is found that the relations

$$p\,D_n = \text{const.} \quad (8)$$
$$i_n/p^2 = \text{const.} \quad (9)$$

are approximately true for a given gas and electrode material. This may be written

$$D_n = \frac{\alpha}{\sqrt{i_n}} + \frac{\beta}{p} \quad (10)$$

where $\alpha$ and $\beta$ are constants. $\alpha$ does not vary much from gas to gas, but $\beta$ varies widely. $D_n$ is the thickness of the Crookes dark space, $i_n$ is the normal current density and $p$ is the gas pressure within the tube.

It seems probable that the primary dark space, when it occurs, represents the distance through which electrons have fallen before acquiring energy sufficient to excite the gas, and this explains its intense blackness. The main cathode dark space is only relatively black, some visible radiation originating therein.

No completely satisfactory explanation of the cathode glow has been offered, but when this is confined to a very thin sheath of light on the cathode surface, it may be due to excitation of a film of gas adsorbed on the electrode. If the surface has been sensitised, for example, with an alkali or alkaline earth metal, the spectrum of this often appears in the glow.

The accurate measurement of the "normal" cathode fall of potential is not easy, but experiments indicate that for a given gas it is approximately independent of gas pressure. When various cathodes are compared and arranged in order of increasing cathode fall, it is found that this is also the order of increasing work function , $\phi_e$, of the electrode materials.

It has already been mentioned that in passing from "normal" to "abnormal" conditions the cathode dark space contracts and the cathode fall of potential rises. With these conditions, and high discharge currents, considerable energy is dissipated as heat at the cathode. The watts dissipated are given approximately by the product of tube current and the cathode fall of potential.

If the current is sufficiently high the cathode may fuse. At current densities considerably less than this value, disintegration of the cathode takes place, and a deposit of "sputtered" cathode material forms on the walls of the tube. The rate of sputtering increases rapidly with current density, cathode fall of potential, and molecular weight of the gas concerned. It is independent of the temperature of the cathode, providing this is itself not high enough for evaporation to take place, and is due almost entirely to the impact of fast moving positive ions on the cathode. Occasionally the temporary formation of compounds of the gas and the cathode material occurs. In the following table various metals have been grouped in order of intensity of sputtering in the Argon discharge, the effect diminishing from left to right.

Table 2.

Ag, Au, Sn, Cu, Pt, Ni, Fe, W, Al, Mg.

The above order is somewhat modified in other gases.

### (10)—THE NEGATIVE GLOW AND THE FARADAY DARK SPACE.

The nearly uniform thickness of the cathode dark space makes the negative glow follow closely the contour of the cathode, but if the current density is higher over any section of the latter, the negative glow expands slightly towards the cathode in this region. The glow is not uniformly bright throughout its length, the visual intensity falling away sharply towards the cathode, and more gradually to the Faraday dark space, from a maximum near the negative face. The colour of the negative glow is different for each pure gas filling, but tiny traces of impurity make considerable changes in this colour, and, in addition, lines in the spectrum of the cathode material itself frequently appear in the glow. This seems to indicate that sputtering takes place atom by atom. By the use of exploring electrodes, considerable progress has been made in the understanding of the negative glow. It is found that the brightest part of the glow is the region of the highest concentration of both electrons and positive ions in the discharge (scme $10^{11}$ to $10^{12}$ per cc.). In the glow itself there may be two groups of electrons with different "temperatures," but these merge into one as the Faraday dark space is approached, the electronic energy falling off meanwhile. There is also evidence of the presence of electrons of higher energy, approximately equal to that of the ionisation potential of the gas, near the negative face of the glow. The large concentration gradient of electrons and ions on either side of the brightest region of the glow results in diffusion effects which may be sufficient to carry the electrons and ions against the reversed electric fields which may be found in this region of the discharge. This effect, however, will be considered in more detail in the section dealing with hot cathode discharges. It is not yet certain whether the radiation in the negative glow follows excitation of neutral atoms, or is due to recombination of ions and electrons previously formed, but direct excitation is likely to be the more important of the two processes. Little need be said about the Faraday dark space, except that the electronic energy and the direct electric field both increase as the positive column is approached. The boundary between the negative glow and the Faraday dark space is rather indeterminate, since the change

of concentration of ions and electrons, and thus of the radiation processes which make the visual boundary, is small.

### (11)—THE POSITIVE COLUMN AND THE ANODE GLOW.

At a given gas pressure the length of discharge occupied by the cathode phenomena, the negative glow and the Faraday dark space, is fixed, and the remainder of the tube is occupied by the positive column and the anode glow, if one is present, together occasionally with a small dark space separating them. Descriptions of the many highly complicated forms which the positive column may assume have already been given. It seems probable that with inert gases in an absolutely pure state, no striation or other breaking up of the positive column would occur, and that all such phenomena can be traced to the presence of impurities in the gas.

The uniform positive column is a region of nearly constant potential gradient, sufficient to maintain the generation of positive ions and electrons as these are withdrawn towards the cathode and anode respectively. The spectrum of the column indicates that but little recombination of these ions and electrons takes place. Although usually thought of as a highly luminous region, the positive column in a wide tube may be comparatively insignificant. The longitudinal potential gradient then depends almost entirely upon the nature of the gas and its pressure. In narrow tubes, however, a sheath of positive ions forms on the walls of the tube and affects the field in the discharge. The longitudinal potential gradient now depends on the diameter of the tube and the current density, in addition to the pressure and nature of the gas. To a first approximation the product of tube diameter and potential gradient is constant, and this product decreases with increasing current density. It can be shown theoretically that these relations should be true.

In the striated positive column, different types of striations appear under fairly definite conditions of current density and gas pressure. In each striation, the edge nearest the anode is usually diffuse, and the cathode or negative edge, fairly sharp. The striation often shows concavity towards the anode. A maximum of visual intensity usually occurs near the negative edge, as in the negative glow. The field throughout a striated column has been measured by moving the anode through the discharge and noting the decrease of discharge potential as each striation is absorbed in the electrode, also by measuring the deflection of a beam of electrons passing across the column. Perhaps the most accurate measurements have been made by the probe method which has largely confirmed the earlier work. The potential throughout each striation is nearly constant, and there is an increase of potential between successive striations, approximating to the ionisation potential of the gas. The concentration of ions and electrons rises to a maximum near the region of greater visual intensity in each striation, very much as in the negative glow, but the concentrations are about $\frac{1}{100}$th of those occurring in that region, and the electronic energies amount to about one half the ionisation potential of the gas. It is assumed that slow electrons move towards the anode in the nearly uniform field acquiring energy as they do so, until they are able to excite or to ionise atoms with which they collide. In doing this they lose much of their energy and the drift commences again until fresh excitation occurs some distance away. In this manner regions with a high concentration of electrons and ions are formed at equal distances apart, and these constitute the bright portions of the striations. The rôle of the impurities appears to be largely to inhibit or destroy the metastable excited atoms which, having a life some $10^5$ to $10^6$ times that of the ordinary excited atom, might diffuse throughout the column. Obviously striations cannot occur unless the excitation is confined to certain sharply defined regions.

Examination in a rotating mirror of a long positive column tube, filled with an inert gas and operating at a high current density often shows that the apparently uniform luminous column is in reality made up of striations moving with high velocity away from the anode. It is possible that if two such sets of striations exist simultaneously, the total effect may be that of a single stationary striated column.

The anode may be free from glow, or covered with a uniform sheet, or with one or more balls of light, usually arranged in symmetrical patterns on its surface. This latter condition seems to be closely bound up with gas layers on the surface. When no glow is present there may be no anode fall of potential, but when the glow occurs there is often a potential drop of approximately the ionisation potential of the gas. In certain cases, *e.g.*, a constricted discharge in front of the anode, the anode fall of potential may be much higher, and in other cases it may be negative.

# The New Subway Line of the Buenos Aires Terminal Central Railway.

By A. H. JACKSON.

Traction Department of The General Electric Co., Ltd.

ONE of the most important underground railway electrification schemes recently completed overseas is that of the new subway line of the Buenos Aires Terminal Central Railway, the first section of which—from the terminus of the Buenos Aires Central Railway to Calle Callao, a track length of approximately five miles—was opened for public traffic on the 18th October, 1930, by the President of the Argentine Republic at the invitation of Dr. Teofilo Lacroze, the president of the Buenos Aires Central Railway.

As the circumstances which surround the inception of the scheme are of some interest, it is proposed briefly to review them before passing on to a detailed description of the railway itself.

Only sixty years ago, Buenos Aires was a comparatively small town with a population of 177,000. Since then this figure has been doubled every fifteen years until, at the present time, the capital of Argentina is the tenth largest city in the world, having a still rapidly growing population of 2¼ millions. Such rapid growth has brought in its wake many problems, of which road traffic congestion is one of the most serious.

As with almost every other large city in the world, the nucleus from which Buenos Aires has grown and round which it now centres, was not originally planned to meet the heavy traffic demands of to-day. Many of the streets are old and narrow and are quite unsuitable for heavy tramway or bus traffic. The traffic congestion is probably most serious in the region of Calle Corrientes, one of the most important of the city's main traffic arteries, in the district surrounding which are situated the chief business houses, departmental stores, clubs, restaurants, theatres and cinemas.

Fig. 1.—Road traffic in Buenos Aires.

The only solution to the problem being the construction of an underground railway, Messrs. Lacroze Bros. applied for, and obtained in 1912, a concession to build a subway line from the terminus of the Buenos Aires Central Railway at Federico Lacroze, along Triumviarto and thence along the whole length of the Corrientes, the main thoroughfare, to the Port. Some years later, however, the Argentine Government sanctioned the transfer of the concession to the Buenos Aires Central Railroad and Terminal Company, under whose management the construction of the underground railway has been completed.

In the accompanying map, fig. 2, the route of the new railway is shown in relation to other railways and to the main streets of the city. The eleven stations are located at intervals of approximately ½-mile along the five miles of track between the two termini, the normal running time from one end of the line to the other being approximately 18 minutes.

As a uniform fare is charged for a journey of any distance on the underground, the need for booking offices at the various stations is eliminated, and passengers, after inserting a coin in a receptacle at the turnstile, pass immediately to the escalators.

Unlike most of the railways running in to Buenos Aires, the Central Railway uses a standard gauge track of 4ft. 8½ins. The new underground railway is also built with the same gauge track, so that passengers arriving at Federico Lacroze on the main line will be able to continue on the under-

ground beneath Corrientes, thus providing direct access to the business and shopping centre of the city. Moreover, passengers from the International Expresses from Entre Rios, and from the Argentine North Eastern Railway, will also be able to use the underground to the centre of the city.

With these coaches, one of which is illustrated in fig. 5, it was estimated that a 3-minute service during the day and a 5-minute service at night would enable the railway to carry 200,000 passengers per day or 75,000,000 per annum. During rush-hours, the service could be increased to a 1½-minute schedule.

Fig. 2.—Map of Buenos Aires showing railway systems.

In planning the new railway, considerations of intensive passenger traffic had to be taken into account, necessitating a special design of coach. Tenders were invited from all parts of the world, and it is gratifying to record that, in the face of severe competition, the contract for the construction of

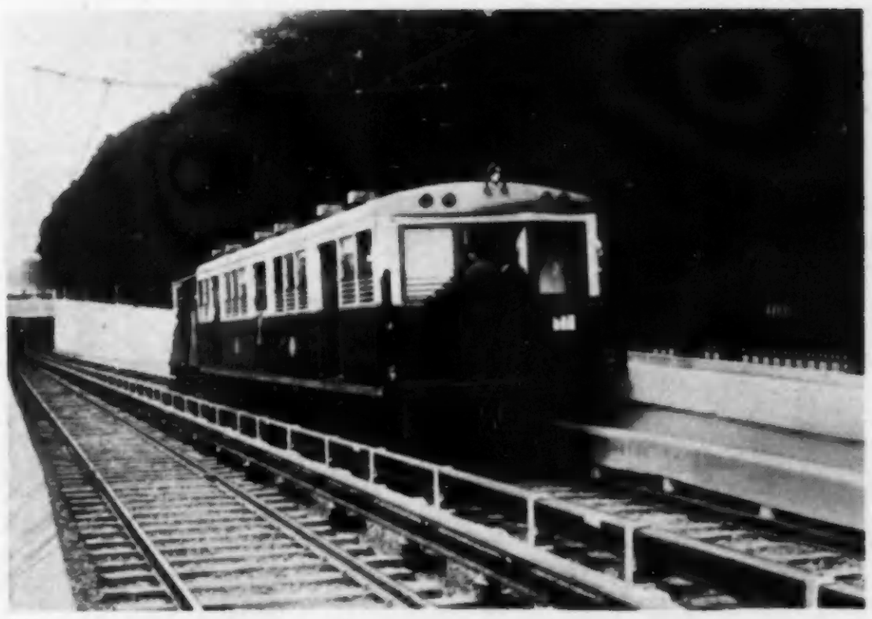


Fig. 3.—One of the new motor coaches undergoing trials on the gradient outside Federico Lacroze.

56 all-steel electric motor coaches, each driven by two 105 h.p. motors, electro-pneumatically controlled, was awarded to British manufacturers, the coach bodies and bogies being supplied by the Metropolitan-Cammell Carriage, Wagon & Finance Co., Ltd. of Saltley, Birmingham and the electrical equipment jointly by The General Electric Co., Ltd., and Les Ateliers de Construction Oerlikon.

It is interesting to compare this estimate with the actual figures obtained on the opening of the first section of the system on the 18th October, 1930. On the first day, 183,000 passengers were carried and on the second day 196,000, with only 31 of the 56 coaches in operation. During these two days

Fig. 4.—Pueyrredon Station, showing turnstiles and escalators.

more than 200 passengers per car were carried on some of the trains, a fact which indicates the capability of the rolling stock for dealing with exceptional traffic conditions.

### PRINCIPAL DIMENSIONS.

The cars are of special construction designed for rapid transit subway service, each being a motor

coach provided with a driving compartment at each end, so that any number of cars may be coupled together to form a train. The following are the leading dimensions :—

| | |
|---|---|
| Length over coupler faces .. | 54ft. 9 7/16ins. |
| Length over anti-collision bumpers | 54ft. 4 7/16ins. |
| Length over roof .. .. .. | 53ft. 11½ins. |
| Distance between bogie centres | 37ft. 4 7/16ins. |

With the exception of the wooden seats and seat backs the construction of the coaches is of steel throughout.

**BODY FRAMING.**

The body side framing consists of steel pillars, 2¾ins. deep, the exterior panels being riveted to these as well as to the solebars. Metal-framed drop lights are provided, arranged with special roller locks to

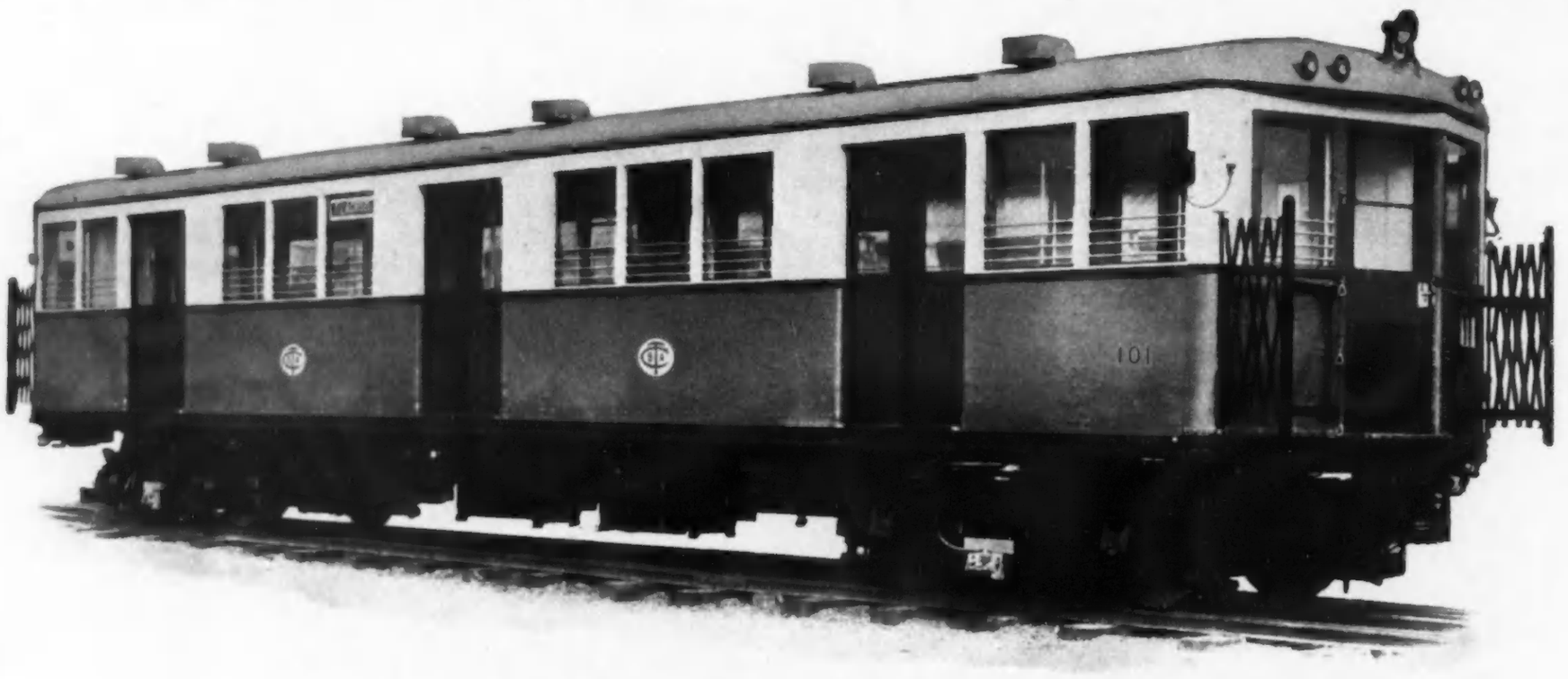


**Fig. 5.—General view of one of the 56 motor coaches.**

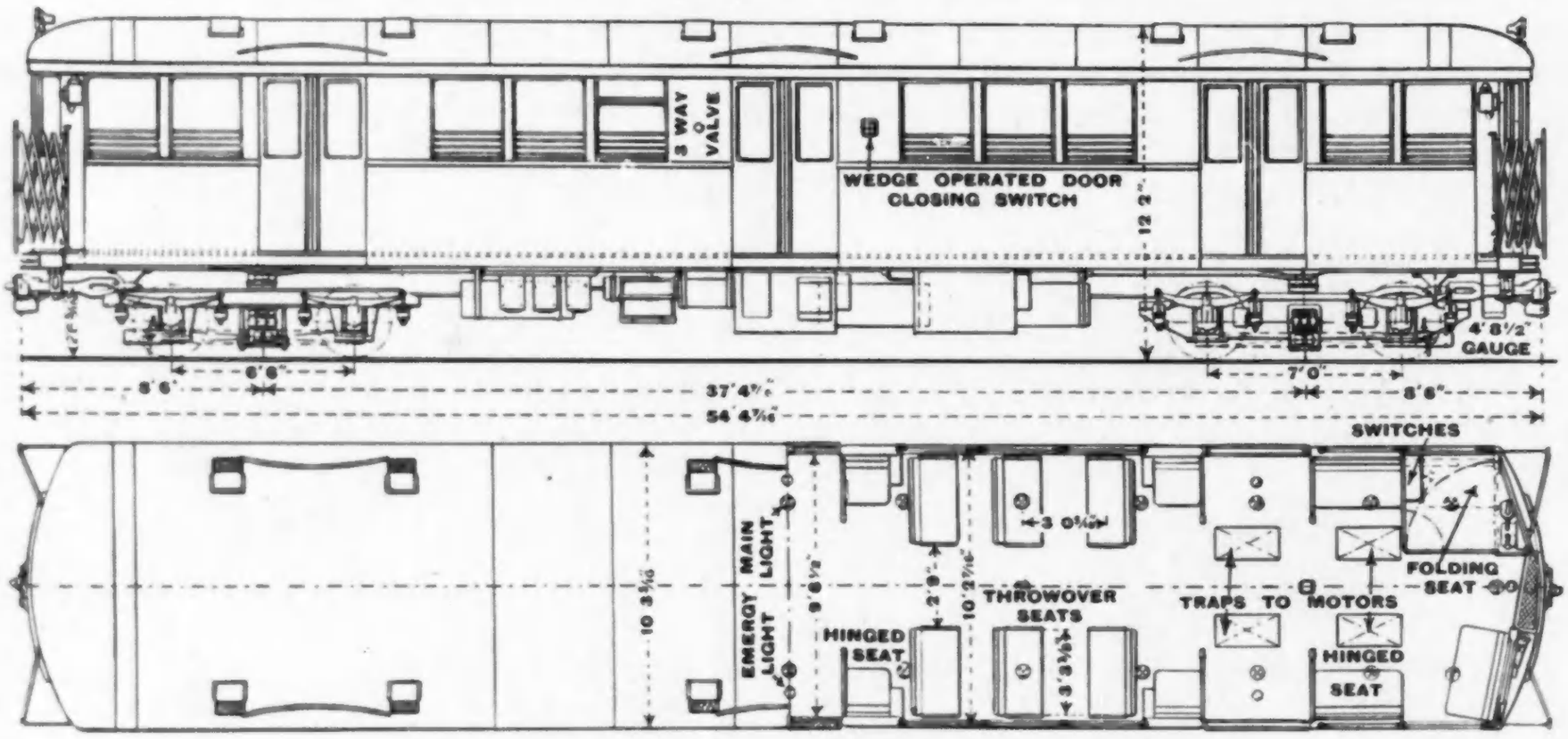



**Fig. 6.—Elevation and plan of a coach, giving principal dimensions.**

| | |
|---|---|
| Motor bogie wheel base .. .. | 7ft. oins. |
| Trailer bogies wheel base .. .. | 6ft. 6ins. |
| Height from rail to top of roof .. | 12ft. 2ins. |
| Width over body side sheets .. | 10ft. 2 7/16ins. |
| Height from rail to top of floor .. | 3ft. 10ins. |
| Height from floor to cant rail .. | 6ft. 11ins. |
| Height from rail to centre of coupler | 2ft. 6 5/16ins. |
| Driving wheel diameter .. .. | 34ins. |
| Weight of complete coach with all equipment, but excluding passengers | 72,000 lbs. |

hold the window in any desired position. The interior waist panels finish short of the floor in order to allow free air circulation.

Two destination indicators are fitted in the body side above the drop lights, while six side doorways, fitted with double sliding doors, giving a clear opening, 3ft. 10ins. wide, are provided. The doors, which are of built-up aluminium, fitted with rubber safety edges, are automatically operated by electrically controlled air engines.

Adequate ventilation is provided by the mounting on the roof of twelve large honeycomb type ventilators with metal shutter regulators.

The ends of the car are of special contour to allow for a platform from which the handbrake may be operated, while a sliding door in the centre gives access to the next car, the gangway being protected by leather-covered safety chains. Spring safety gates are also fitted to the ends of the cars in order to prevent passengers falling on to the track between the cars when the trains are loading at stations.

### DRIVING COMPARTMENTS.

A driving compartment is provided at each end of the car, wherein all the necessary controls, brake valves, door signals, etc., are housed. This compartment is formed by hinged partitions built up of aluminium sheets and duralumin bars so arranged that when the driving ends of the coach are not being used for driving purposes, the partitions may be folded up, totally enclosing the controls. A folding seat is then lifted into position, thereby providing more seating accommodation for passengers.

### SEATING ARRANGEMENTS AND DOOR OPERATING EQUIPMENT.

Each car is capable of seating 47 passengers and, during rush hours, carrying over 200 passengers, seated and standing. In order to provide the necessary accommodation for this large number, the seating arrangements have received special consideration. All the longitudinal seats in each coach are fixed, while the cross seats are of the throw-over type. The seating arrangements are clearly indicated in figs. 6 and 7.

The double-acting automatic doors are so arranged that when the coaches are in motion, they are securely held in the closed position by air pressure. By pulling the emergency cord to stop the train, however, the doors are immediately released so that there is no danger of passengers being trapped in the coaches in emergencies.

The doors are controlled electrically from push button control boxes mounted in the centre door windscreen panels of each car. The system provides for multiple-unit working in its most elaborate form and, by the setting of simple key-operated conversion switches, a train may be divided into "door control sections" of any desired number of cars, according to traffic conditions and the number of guards available.

**Fig. 7.—Interior of one of the coaches illustrating seating arrangements and lighting equipment.**

In order to prevent overcrowding of any individual coach, exterior switches are provided by means of which a member of the platform staff, equipped with an operating key, may close the doors of the particular car.

When all the doors are fully closed in any door-control section the fact is indicated to the guard concerned by a lamp, a similar indication informing the driver when all the doors on the train are closed. By means of a relay inserted in the feed circuit of the master controller in use it is impossible to start the train with any door open.

Similarly, should a door be opened during a journey the train would automatically be brought to a standstill.

### BOGIE ARRANGEMENT AND BRAKE EQUIPMENT.

Each car is carried on one motor bogie (fig. 8), and one trailer bogie. The motor bogies are each equipped with two axle-hung motors which drive spur wheels shrunk on to the axles of the driving wheels.

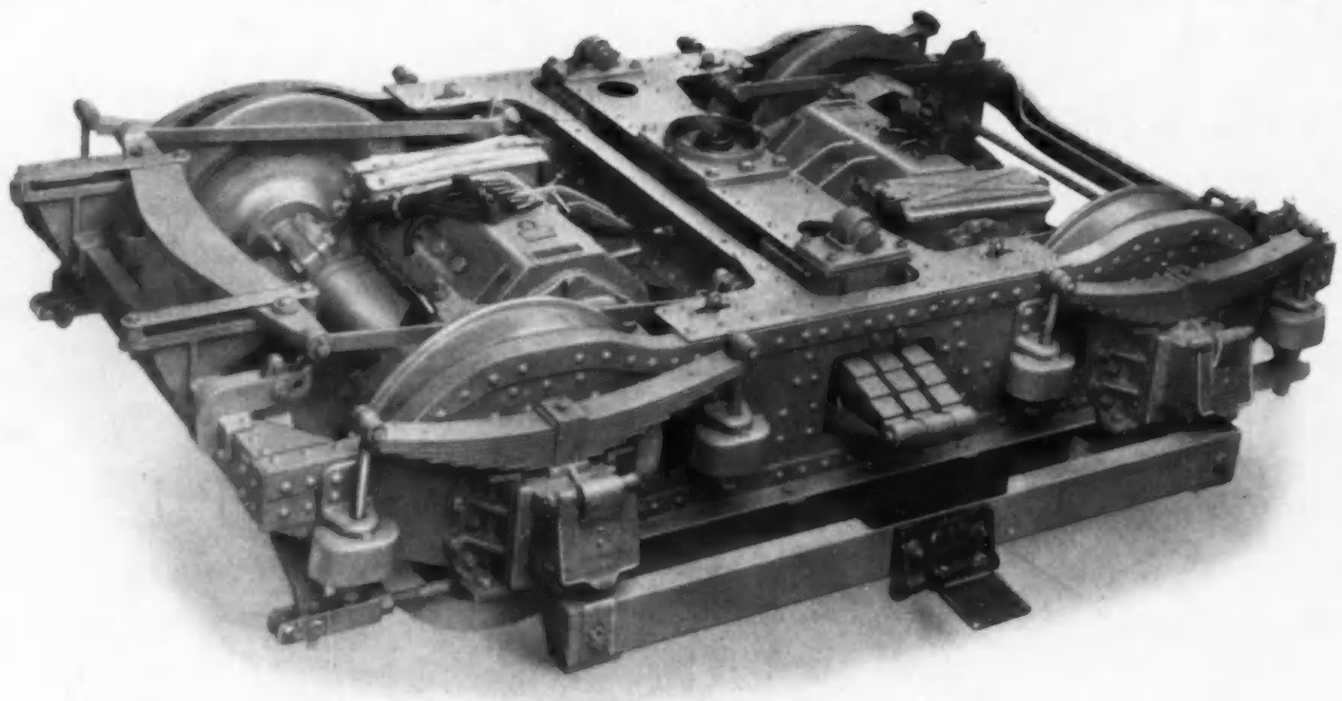


**Fig. 8.—One of the motor bogies.**

Electro-pneumatic brakes, with a variable load feature, are installed, the compressed air for their operation being provided by a compressor driven from the line supply. The governors controlling the compressors are synchronised throughout the train as described later.

As each coach is a motor-coach and has a driving position at each end (fig. 9), a drivers' brake valve is provided at each position, from which the brakes can be released, held partially applied, applied for service, or applied for emergency.

The brakes are normally operated electrically by the energization of magnets on each car from contacts on the operative driver's brake valve; consequently all brake operations occur simultaneously on each car in the train. The driver's brake valve also contains a pneumatic portion which repeats the electrical functions, raising and lowering the brake pipe pressure in synchronism with the degree of application of the brakes. Thus, should an electrical failure occur, the brakes will operate pneumatically without any further action on the part of the driver. Each car is provided with a universal valve which links up the electric and pneumatic operation, translating the various control operations into the corresponding braking operations.

### FACTORS GOVERNING DESIGN OF ELECTRICAL EQUIPMENT.

In describing the electrical equipment it is first necessary to refer to the principal service conditions specified for the coaches. Briefly these are as follows :—

| | |
|---|---|
| Max. voltage at third rail .. | 560 volts D.C. |
| Average voltage at third rail during peak hours .. .. | 500 „ „ |
| Acceleration during peak hours on level tangent track .. | 1.4 m.p.h. p.s. |
| Braking rate .. .. .. | 1.9 „ „ |

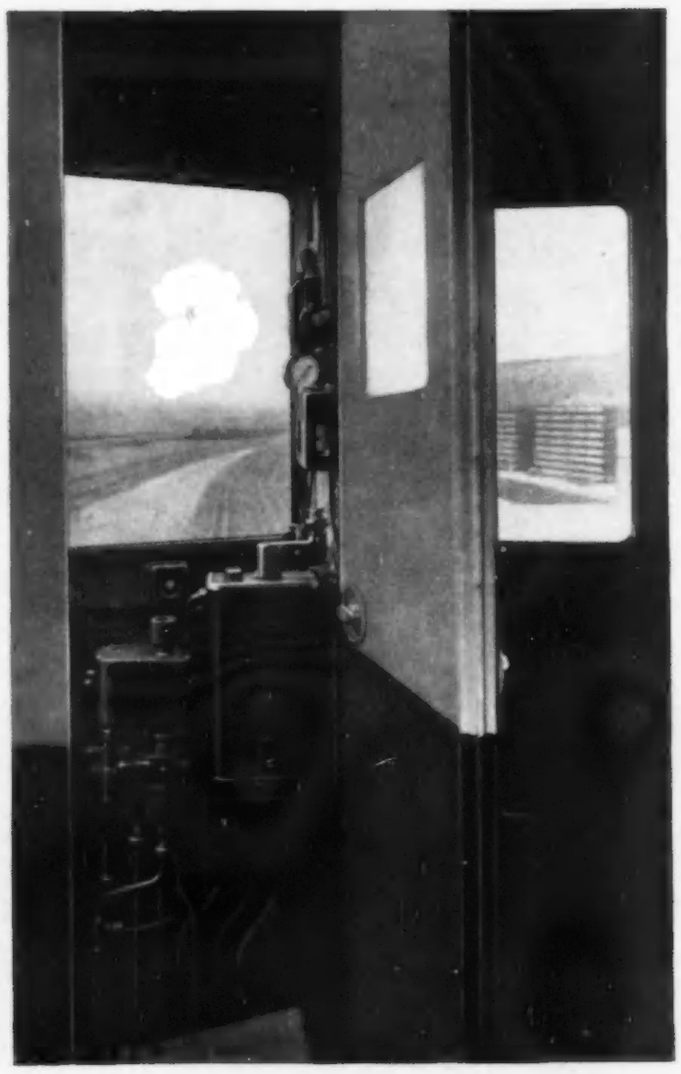


**Fig. 9.—Interior of driver's compartment showing controls.**

| | |
|---|---|
| Number of stations including termini | 12 |
| Average length of station stop .. | 20 secs. |
| Total round trip distance .. .. | 15.77 kms. |

| | | |
|---|---|---|
| Stops per mile .. .. .. | 2 approx. | |
| Maximum permissible speed .. | 40 | m.p.h. approx. |
| Max. average speed .. .. | 30 | „ „ |
| Schedule speed .. .. .. | 16 | „ „ |

In order to fulfil these requirements it was necessary to consider the two main governing factors —normal and rush-hour service. The normal service comprises the operation of trains with an average load of 47 passengers per coach and a total running time of 36 minutes for the round trip ; also individual station-to-station runs including a period of coasting.

With the rush-hour service the cars are loaded to full capacity. In these circumstances, the total number of standing and seated passengers averages 100, and owing to the large number of passengers entering and leaving the coaches, the station stops extend beyond the normal allowance of 20 seconds. The train has then to be driven at a higher speed between stations in order to maintain the schedule speed. Under these conditions, coasting is eliminated, current being fed to the motors up to the point of application of the brakes.

In selecting the most suitable traction motor for the service, three factors had to be borne in mind, namely, energy consumption, temperature rise of the motors in service, and peak currents during starting.

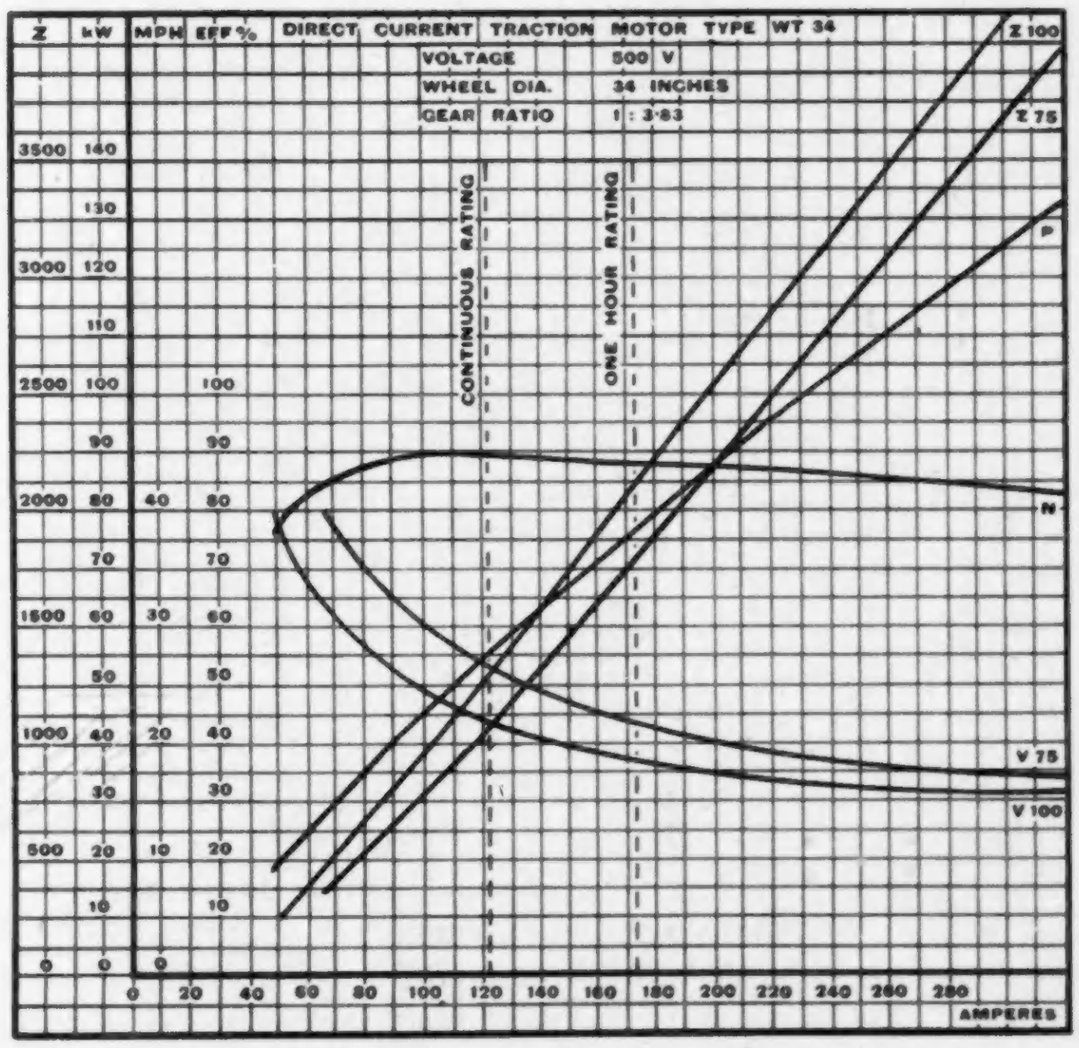



Fig. 10.—Technical details of traction motors.

P=Output in kW at wheel Z=Tractive effort in lbs. at wheel
N=Per cent efficiency with gear V=Speed in miles per hour
Indices 100 : 75 = Per cent excitation.

RATINGS AT MOTOR SHAFT

| | Continuous | One Hour |
|---|---|---|
| Motor Current .. .. | 122 amps. .. .. | 173 amps. |
| Output .. .. | 56 (75) kW (h.p.) | 78.5 (105) kW (h.p.) |
| Speed .. .. .. .. | 21.6 m.p.h. .. .. | 18.5 m.p.h. |

From the point of view of energy consumption the normal service duty is more important than the rush-hour condition, owing to the temporary nature of the latter. From the point of view of heating of the motors, however, the rush-hour condition is the more important.

The train equipments are arranged for automatic acceleration, the relays being given a definite setting

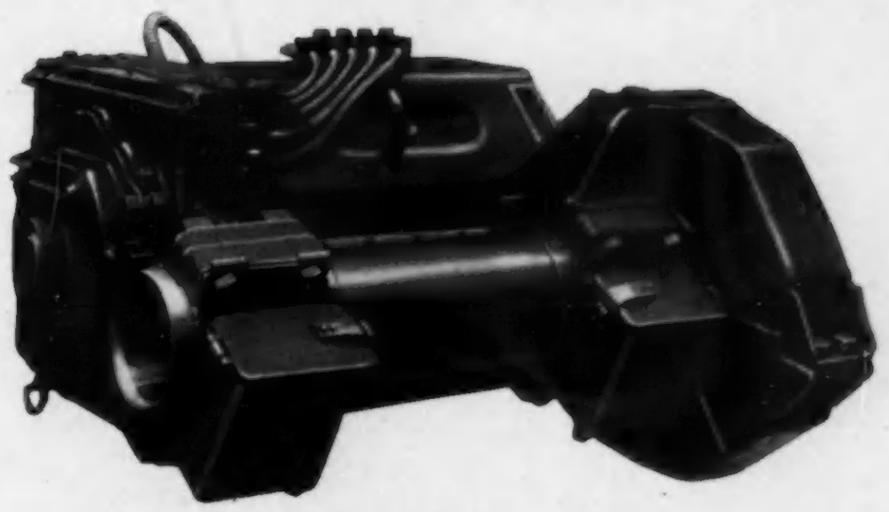


Fig. 11.—105 h.p. traction motor : two are installed in each coach.

corresponding to a starting acceleration of 1.4 m.p.h.p.s. on level tangent track, so that the average starting current is the same for both normal and emergency service.

The motor characteristics (fig. 10) were therefore chosen to yield the most favourable compromise between the three desiderata. It was specified that the traction motor speed on the one-hour rating should be approximately 700 r.p.m. at 500 volts, and on the basis of this armature speed it was possible to choose one of several gear ratios. Eventually a ratio of 18/69 was adopted.

## TRACTION MOTORS.

The traction motors installed in the coaches are of the self-ventilated, interpole, series wound, field-control type. One of these motors is shown in fig. 11.

The motors are arranged for operation at 560 volts, D.C. the ratings, in accordance with British Standard Specification No. 173 of 1928, being as follows :—

One hour rating—105 b.h.p., 500 volts, 173 amps., 684 r.p.m.

Continuous rating—75 b.h.p., 300 volts, 122 amps., 502 r.p.m.

Tapped field control is employed, the motors being provided with one tapping of 75 per cent. of the full field turns. Normally, the motors run on the parallel, tapped-field position, full field being used only as an intermediate accelerating condition.

SYSTEM OF CONTROL.

Each coach is provided with four positive shoes, each of which feeds the main 500-volt bus line, which runs the length of the coach, but which is not connected between coaches. The main circuit arrangements are shown in fig. 12. From the bus line the feed passes through the main fuse and branches into separate feeds for the main motor circuits and the auxiliary circuits. The motor

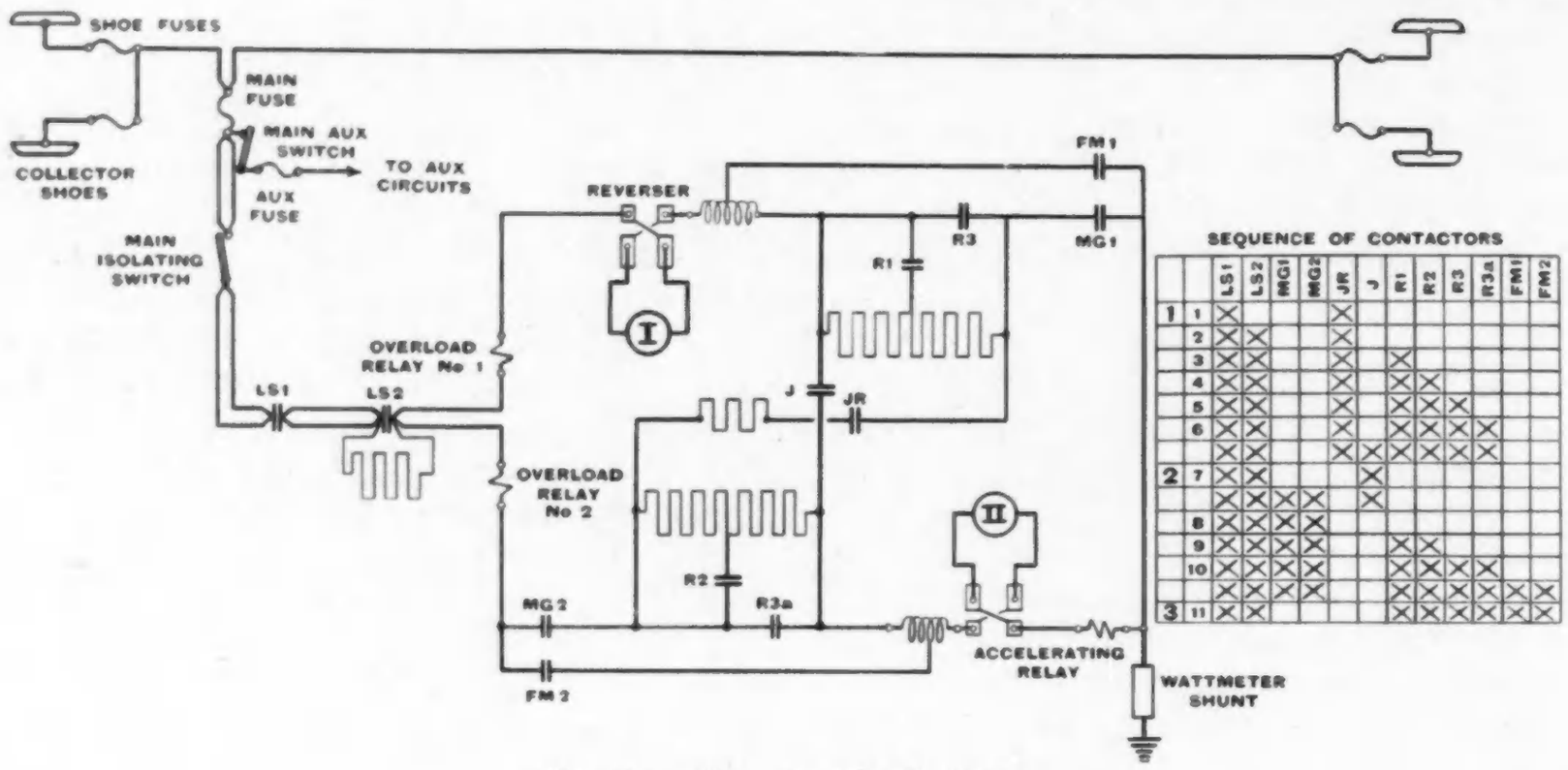



**Fig. 12.—Main circuit diagram.**

circuit feed is taken through an isolating switch so that the main equipment may be isolated while still leaving power on the control circuits. The control gear can thus be operated with the motor circuit dead to ensure that it is in correct working order. From the main isolating switch the motor circuit passes *via* line contactors and overload relays to the main motors and starting resistances with their contactors.

Overload protection is provided by an overload relay in each of the two legs of the main motor circuit. These relays operate on the line contactors.

A particularly simple arrangement of main motor control is employed, using a minimum number of contacts, sufficient resistance steps being provided to ensure smooth acceleration under all conditions. Contactors are also provided for tapped field control of the motors, bridge transition being employed. The automatic acceleration of the motors is controlled by a current limit relay.

UNDERCAR-MOUNTED CONTROL APPARATUS.

The control apparatus is housed in two separate cases. The first case contains two resistance contactors, two series-parallel contactors, one field tap contactor and two line-switch contactors, the line-switch contactors being provided with arc chutes having direct ventilation to the atmosphere. On the end of this case the two overload relays are arranged. The second case contains two resistance contactors, two series-parallel contactors, one field tap contactor and the reverser. On the end of this case are mounted the current limit relay, the compressor contactor and the battery contactor.

The main resistances are of the cast iron grid type assembled in frames and, together with the two control cases, are suspended from the coach underframe (fig. 13), the location of the individual items of the apparatus being such that a uniform distribution of weight is obtained.

DRIVING COMPARTMENT CONTROLS.

The main isolating switch is housed in a switch cabinet in one of the driving compartments on a partition well behind the driver. This cabinet also houses the compressor switch and fuse and the compressor governor cutout switch, together with other auxiliary control gear.

The general arrangement of the master controller, with the electro-pneumatic brake valve control and the overload relay reset push button is shown in fig. 9, which clearly illustrates the compact nature of the master controller, the control fingers of which are of the compression spring type. Separate reverse and main drums are provided and are interlocked in the usual way, while a dead man's handle is also fitted.

AUXILIARY CIRCUIT.

The compressor, battery charging and main lighting circuits are operated at the full line tension of 500 volts, while the control, emergency lighting, brake and door control circuits are operated from a 32-volt battery.

The 500 volt auxiliary circuits are taken through a main auxiliary fuse and main auxiliary switch. The compressor circuit is provided with a switch for isolation, a fuse for protection and a controlling

contactor. Master governors control the operating coils of the compressor contactor. One of these governors is provided for each compressor. The governors feed a synchronizing wire running through the train, thereby ensuring the simultaneous starting of all compressors irrespective of which compressor governor operates first. This is necessary to ensure correct sharing of the load between the compressors.

The 32-volt battery is automatically charged from the 500-volt line and is controlled by a battery contactor in series with a charging resistance. The coil of this contactor is energized through the contacts of a battery relay, which in turn is controlled by the terminal voltage of the battery.

The main coach lighting is operated at 500 volts, the lamps being arranged five in series across this voltage. Each individual group of lamps is controlled by its own switch and fuse in addition to the main lighting switch. The lights controlled comprise those for the interior lighting of the car, the train number sign light, and the marker and head lights.

Feeds are taken from the 32-volt battery to a control multicore cable running throughout the train, from which connections are taken to the master controller, the electrical contacts on the driver's brake valve and the door controls.

The 32-volt supply to the master controller is

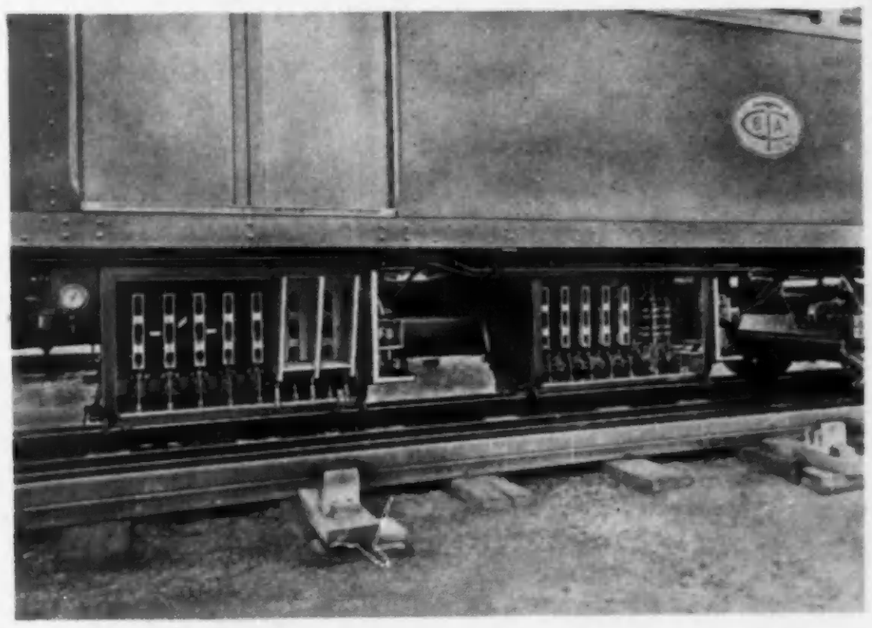


Fig. 13.—Undercar suspension of control apparatus.

taken through suitable fuses and control switches. It also passes through the control governor to prevent the train being started if the air pressure for the brakes is not available at a pre-determined minimum pressure. The feed then passes through the door relay as previously indicated, so that the train can not be started if the doors have not been closed. Indicator lights are provided to indicate to the driver that the doors are closed, and a separate buzzer circuit is arranged so that the guard may communicate with the driver.

### AUTOMATIC COUPLER.

As previously stated, the equipments are arranged for multiple-unit operation. Multicore cable runs throughout each coach and terminates at each end of the underframe in a 39-point automatic coupler. This is illustrated in fig. 14.

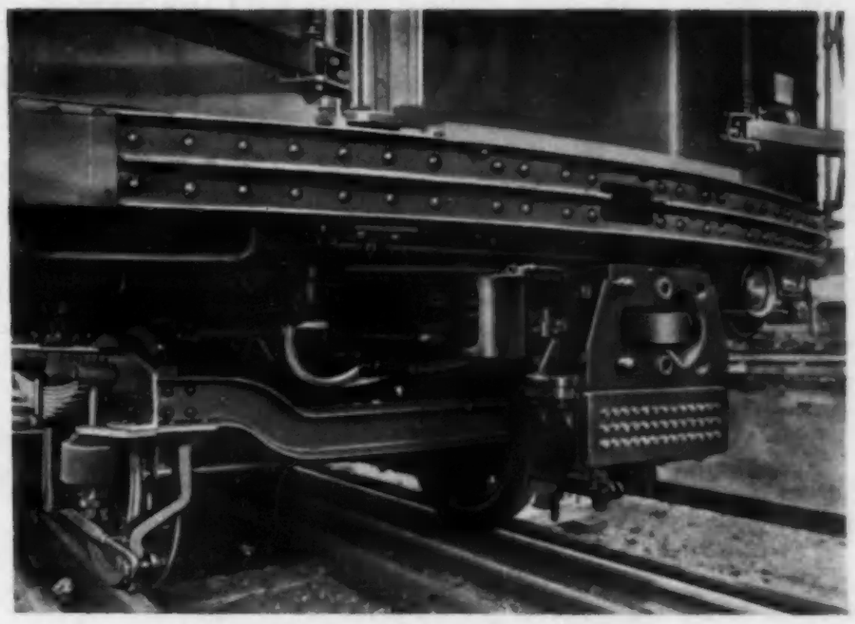


Fig. 14.—End view of under frame showing automatic coupler.

### LIGHTING EQUIPMENT.

Each coach is provided with 30 main interior lights and eight emergency lights operated from the 32-volt battery. The main interior lamps, connected five in series, are of the Osram traction type, each rated at 110 volts, 40 watts, the general design of lamp and fitting being illustrated in fig. 7. Each of the emergency lamps is rated at 32 volts, 25 watts, all eight lamps being wired in parallel.

### TESTING ARRANGEMENTS.

All the cars were completely finished in every respect before despatch, and in order to ensure that they were in correct running order and capable of fulfilling the service conditions as to acceleration, etc., were fully tested on a special electrified track laid by the G.E.C. at the Nottingham Works of the coachbuilders. The cars were then sent direct to port where they were shipped and eventually delivered in Buenos Aires on their own bogies ready for operation.

In conclusion, it should be mentioned that the engineers in charge of the work were Messrs. Dwight P. Robinson & Co. of Buenos Aires, the London technical representative of Messrs. Lacroze being Mr. J. H. Bance, of Iddesleigh House, Westminster, who conducted the inspection arrangements in England.

# The Alternating Current Track Circuit.

By T. AUSTIN, A.M.I.E.E., M.I.R.S.E.

The Siemens and General Electric Railway Signal Co., Ltd.

*Modern railway signalling practice owes its rapid development almost entirely to the track circuit, as it is this element upon which the foundation of any system of automatic or semi-automatic signalling is built.*

*In the following article the author outlines the main requirements and functions of the track circuit, with special reference to new developments in the design of the apparatus employed.*

IN its simplest form the track circuit consists of a length of railway track in which the end rails are electrically insulated from the adjoining rails by insulations assembled at the fish plates. A relay is connected to the rails at one end of the insulated section and a supply of electrical energy to the rails at the other end.

The two running rails act as conductors, and when the track circuit is clear the relay is energized, closing its top contacts and connecting up the controlling or indicating circuits, as shown in fig. 1.

It will be appreciated, of course, that the sleepers must be electrical insulators, and until the problem of satisfactorily insulating steel sleepers has been solved, the track circuit cannot be used where they are employed.

Some idea of track circuiting conditions will be gained from the following figures, which are resistances measured from rail to rail for ballast not in contact with the rails.

| | Ohms. per 1000-ft. of track. |
|---|---|
| Wet Gravel .. .. .. .. | 2 |
| Dry Gravel .. .. .. .. | 3 |
| Wet broken stone .. .. .. | 4 |
| Dry broken stone .. .. .. | 10 |

A leakage resistance of 4 ohms per 1,000 feet of track is commonly assumed in track circuit calculations, but it should be remembered that all leakage paths are in parallel, and thus a track circuit of 4,000 feet in length would have a ballast resistance of only 1 ohm.

It is essential, therefore, in the interests of economy that the track circuit relay shall require a minimum of energy for its operation.

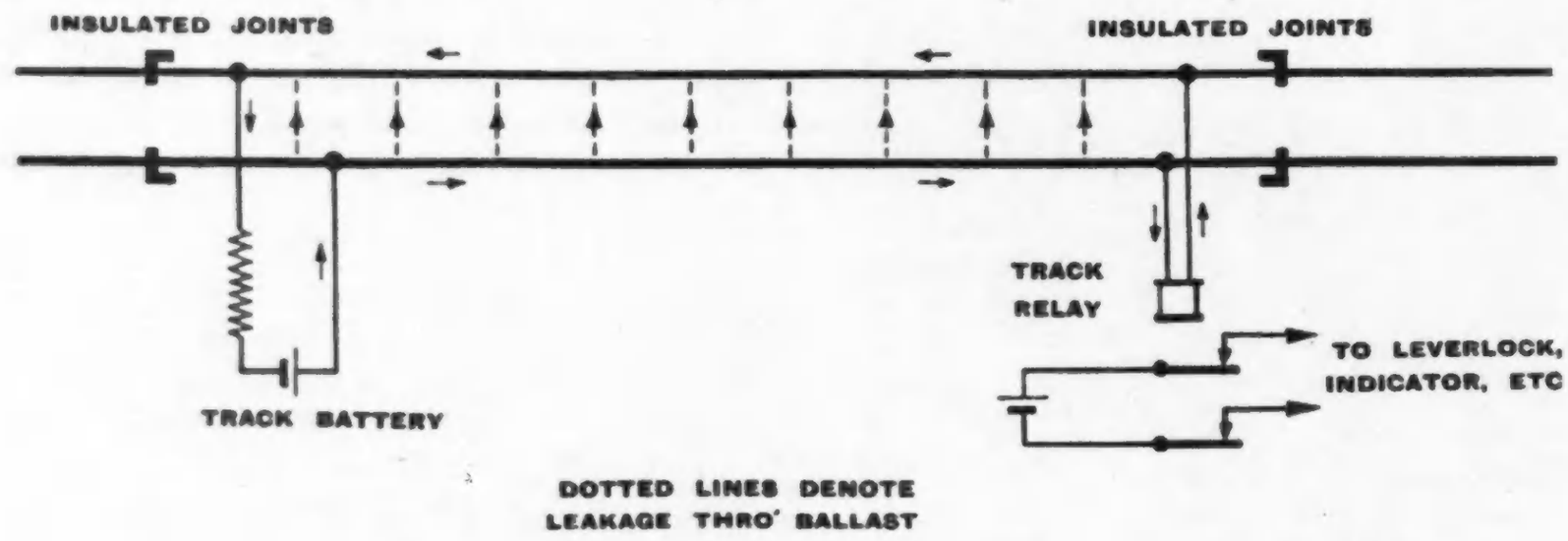



Fig. 1.—Simple track circuit—track clear.

As soon as a train enters the insulated section, a path of low resistance is provided by the wheels and axles and the relay is short circuited, causing its armature to fall away and its top contacts to be opened. This condition is shown in fig. 2.

### BALLAST LEAKAGE.

It should be noted that, in addition to the path through the relay windings, or other apparatus connected across the track, leakage paths for the current are formed through the ballast and the surface of the sleepers, leading to a waste of energy.

### TRAIN SHUNT.

It will be understood from what has already been said that a complete cessation of current in the relay when the track circuit is occupied will be dependent upon the wheels of the train forming an absolute short circuit. Although usually this is so, there are cases, due to sanded, dirty or rusted rails, where a certain amount of resistance may exist in the path of the "train shunt," and under such

conditions a corresponding amount of current may continue to flow through the track relay coils when a train is on the track circuit. It is imperative, therefore, that the track relay shall release its armature with a certain amount of current still flowing through its coils, and the nearer the value of this current is to the "pick up" value, the more efficient the relay will be for track circuit purposes.

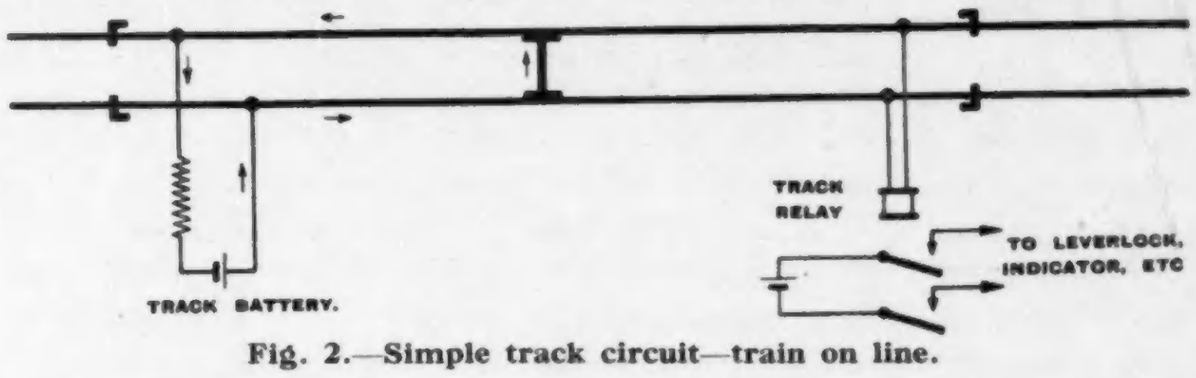



Fig. 2.—Simple track circuit—train on line.

The maximum value ot the resistance which, when connected across the rails, will cause the relay to open its front contacts is termed the "train shunt resistance." Its value will usually be lower in dry weather, when the ballast resistance is high, but under the worst conditions endeavour is made to secure a maximum shunt of not less than 0.5 ohm. For normal track circuits the "train shunt" may be between 2.0 and 3.0 ohms.

### ALTERNATING CURRENT TRACK CIRCUITS.

The use of direct current relays for track circuits on electrified railways employing direct current for traction purposes entails considerable risk, due to the possibility of the relay being wrongly energized by current other than the legitimate track circuit current.

Some of the chief sources of extraneous current are enumerated below.

(1). Potential difference in running rails used for traction purposes.
(2). Faulty insulation of train equipment.
(3). Train contact gear out of gauge, fouling running rails at crossings.
(4). Faulty insulation of traction conductor rail.
(5). Faulty insulation of power cables.

On electrically operated railways, conditions for producing a false "clear" indication are always present during working hours, and it is therefore necessary to employ relays which are immune from being incorrectly operated.

It is now almost universal practice, where stray direct current is likely to be encountered, to use alternating current for track circuits, and it will be apparent that the battery and D.C. relay shown in fig. 1 can be replaced by a source of alternating current and a suitable relay which will not operate on direct current.

### SINGLE RAIL TRACK CIRCUITS.

When track circuits are installed on lines employing electric traction in which the running rails are used as a return for the traction current, provision has to be made for the continuity of this return. This may be accomplished by insulating one rail for track circuiting, and bonding the other rail throughout for the traction current return. This method is quite satisfactory for short track circuits in yards and in the vicinity of points, where sufficient return carrying capacity can be obtained by cross bonding. Further, the single rail track circuit has the advantage of simplicity of insulation, where points and cross-overs render the insulation of double rail track circuits difficult, if not impossible.

The length over which it is possible to operate single rail track circuits is limited, chiefly by reason of the pressure drop in the rail carrying the return traction current. It has the disadvantage also that a break in the continuous rail may not be detected.

A typical single rail track circuit is shown in fig. 3.

### DOUBLE RAIL TRACK CIRCUITS.

With this type of track circuit, both running rails are divided by insulated rail joints into block sections, and where it is necessary to provide for the traction return, the ends of the track circuit are equipped with impedance bonds. Thus, both running rails are made available for traction current, longer track circuits can be operated, and continuous detection of broken rails is afforded.

Such an arrangement is shown diagrammatically in fig. 4.

The impedance bond consists of a laminated iron core around which are wound a number of turns of heavy copper strip of sufficient capacity to carry the maximum traction current. Two separate windings

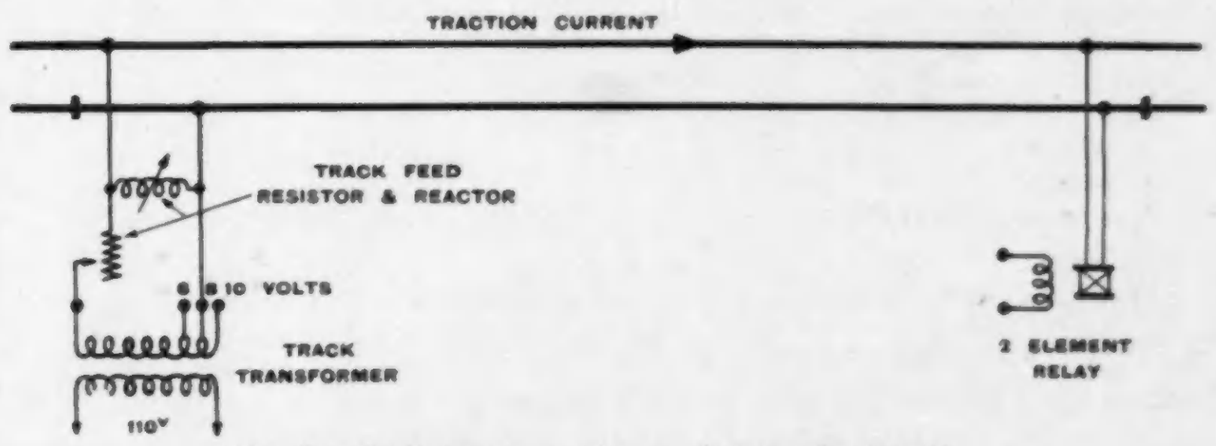



Fig. 3.—Resistance-reactance fed track circuit.

are provided, and these are connected at the centre as shown in fig. 4. The path of the traction current is from the ends of the windings to the centre, or *vice versa*, and gives rise in the core of the bond to two magnetic fluxes, which are, however, in

opposition. If the currents in the rails are identical, the resultant flux will be zero. The signalling current flows from one end of the winding to the other, all the turns being in series, and gives rise to an alternating flux which produces an inductive reactance. Thus, while the impedance bond offers a path of very low resistance to the traction current, it is of sufficiently high impedance to prevent interference with the working of the relay.

**POWER REQUIREMENTS.**

The voltage employed between the rails of a track circuit is limited by the ballast resistance, and as this is usually of a low order the voltage must be low to avoid an undue waste of energy. The value of the track voltage is usually between 0.75 volt and 2.0 volts, and several methods of feeding the current to the rails may be adopted. In every case, however, the following provisions must be made :—

(1). Means to limit the current from the transformer when the track is shunted by a vehicle.

(2). Adjustment by tappings on transformer or on limiting device to obtain ideal values to suit widely varying conditions of ballast—length of track circuit, etc.

(3). Means of adjusting the phase angle of the current supplied to the track circuit. This has a vital bearing on the correct working of the relay.

The above requirements may be met in several ways, depending upon the types of apparatus included in the track circuit.

The current is supplied by means of a small transformer, and in this connection it might be stated that to avoid interference from one track circuit to an adjacent one, each track is supplied from a separate secondary winding.

The voltage is usually transformed from the signalling mains voltage (normally 110 volts) to 6, 8, or 10 volts according to the tapping selected, and is then fed to the track circuit through a resistance or a combination of resistance and reactance.

Another method of feeding now largely in use employs a variable condenser as the limiting device, in which case the voltage is not stepped down, but the full 110 volts is applied to the rails through a condenser of sufficiently high impedance to give the correct values at the rails.

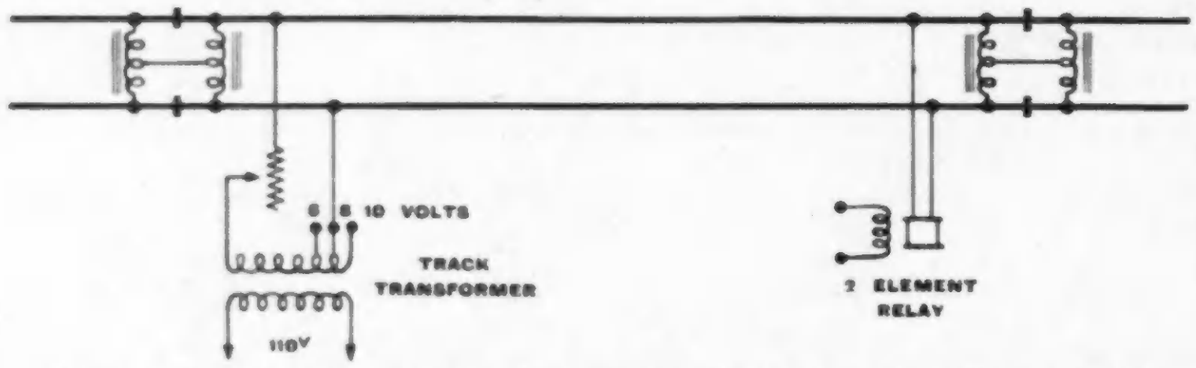



**Fig. 4.—Double rail track circuit using ordinary type impedance bonds.**

Typical power input values for A.C. track circuits are given in the table below. The figures include losses in the regulating device, ballast leak, impedance bond and track winding of relay, and are representative of an average track circuit of 1,000 feet in length.

**TABLE OF POWER INPUT VALUES.**

| Type of Track Circuit. | Volts. | Amps. | Volt/ Amp. | Watts. | Power Factor. |
|---|---|---|---|---|---|
| Reactance Feed .. | 110 | 0.05 | 5.5 | 2.2 | 0.4 lagging |
| Resistance Feed .. | 110 | 0.08 | 8.8 | 5.6 | 0.5 lagging |
| Condenser Feed .. | 110 | 0.50 | 55.0 | 2.75 | 0.05 leading |
| Impedance Bond.. | 110 | 0.8 | 88.0 | 74.0 | 0.82 lagging |
| S.G.E. Auto Bond. | 110 | 0.157 | 18.7 | 14.5 | 0 78 leading |

**IMPEDANCE BOND TRACK CIRCUITS.**

The figures given in the preceding table will make it clear that the inclusion of impedance bonds in a track circuit leads to a large increase in the energy consumption due to the comparatively low impedance of the bonds. Its value is usually of the order of 0.5 ohm. per bond for a 50 cycle signalling supply, and definitely limits the total length of the track circuit which may satisfactorily be worked.

This low impedance is chiefly due to the physical limitations imposed on the design of the bond, *i.e.*, to the small space available in the track for its accommodation. The windings must have sufficient capacity to carry the normal maximum current per rail, but must also be capable of withstanding very heavy overloads for short periods, as, for instance, short circuits caused by faulty train equipment and other causes. In addition, the ohmic resistance to traction current must be very low, as on a section of railway equipped with automatic signalling, a considerable number of bonds may be installed, and consequently, the traction pressure drop would be excessive unless the resistance per bond were strictly limited. The usual allowable limit of resistance for a bond of 1,000 amps. capacity is 0.0004 ohm, this value being measured between the terminals of the bond with both windings in series. As the length of cable connection from the rails to the bond is also limited by the same consideration of pressure drop, it is necessary to accommodate the bonds in the track, usually between the sleepers, this condition determining the maximum size.

Another reason for the low impedance may be found in the air gap which is included in the iron circuit of the bond. The core is provided with a removable yoke, and between the two is placed a non-magnetic spacer. This provision is made to prevent the core becoming saturated by out-of-balance current. As previously mentioned, the traction current flows in the two halves of the windings in opposite directions, and, if both currents are equal, no resultant flux is produced in the core. If, however, the ohmic resistance is less on one rail

than the other, unequal currents will flow through the two windings. This inequality may be due to several causes, such as faulty rail joint bonds, worn rails, or may be due to the curvature of the track, the inner rail of the curve carrying more current than the outer.

It is usual for the impedance bonds to be designed to permit the traction current to be unbalanced to the extent of 20 per cent of its normal full load value, without allowing the resultant flux to saturate the core, and thus reduce the impedance to the signalling current to an undesirable extent.

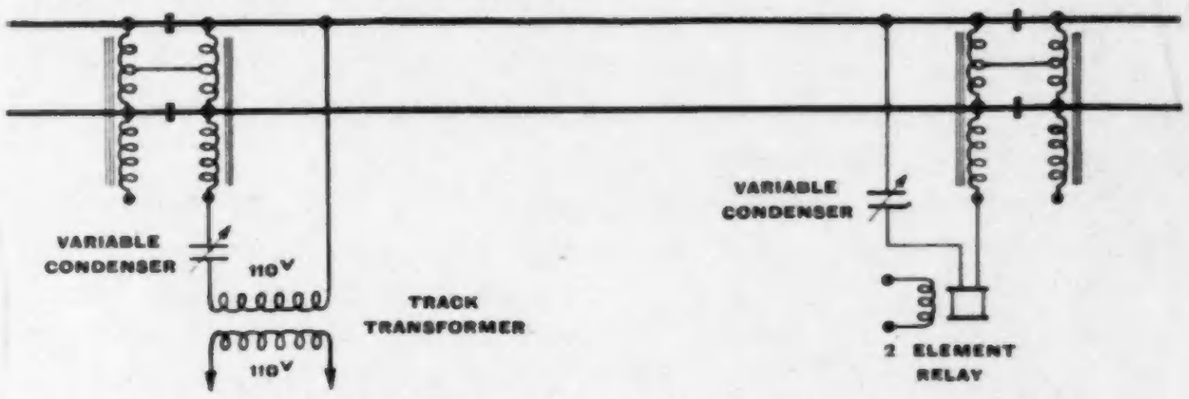



Fig. 5.—Double rail track circuit using "S.G.E." auto bonds.

### THE S.G.E. AUTO BOND.

To overcome the inherent disadvantages of the ordinary impedance bond The Siemens and General Electric Railway Signal Company have designed a new type of bond, known as the Auto Bond. Its use permits of the employment of long, double rail track circuits, with improved train shunts, while at the same time, the total power input is considerably reduced.

The general construction of the Auto Bond is similar to the ordinary impedance bond, but in addition to the traction winding it has an auxiliary winding on the same core. The Auto Bond thus functions as an impedance bond and as an auto-transformer, with special characteristics. The diagram for a track circuit equipped with Auto Bonds is shown in fig. 5.

In this case a departure is made, in that, instead of feeding the track circuit at low voltage through a regulating resistance, a voltage of 110 is employed and a variable condenser is included in the track feed. A similar type of condenser is also connected in series with the track winding of the relay.

The employment of a variable condenser at each end of the track circuit enables ideal phase relationship to be obtained in the relay, and renders possible the use of stable train shunts of high value, even with poor ballast conditions. Further, the presence of these condensers prevents any stray or unbalanced direct current flowing through the windings of the relay or transformer. Another important feature of this type of track circuit arises from the fact that the line resistance of the track leads and of the relay leads does not affect the operation of the track circuit—an important consideration affecting the housing of the relays, condensers and the like.

The total power consumption of the Auto Bond track circuit, including all losses in bonds, ballast leak, etc., is very low, varying from about 2 watts in the case of a short track circuit to about 20 watts in the case of track circuit 6,000 feet in length. Auto Bond track circuits up to 15,000 feet in length are being operated with every success.

### APPARATUS EMPLOYED.

RELAYS.—Many types of A.C. relays have been designed since the A.C. track circuit was first introduced, but the relay in general use to-day is of the "vane" type.

The vane relay is made in two forms, *i.e.*, single element and double element, both of which work on the same fundamental principle, namely, the induction of eddy currents in a vane or disc of non-magnetic material.

The single element relay, as its name implies, has only one winding, and, as all the power required by the relay has to be derived from the track circuit, its use is restricted to very short track circuits, and then only when the ballast resistance is high. Its power consumption is approximately 8 watts for a relay having six front contacts.

The double element relay is now almost universally used for track circuit work on account of its economy of working and its immunity from operation by any current other than its legitimate supply. It is provided with two distinct windings or elements,

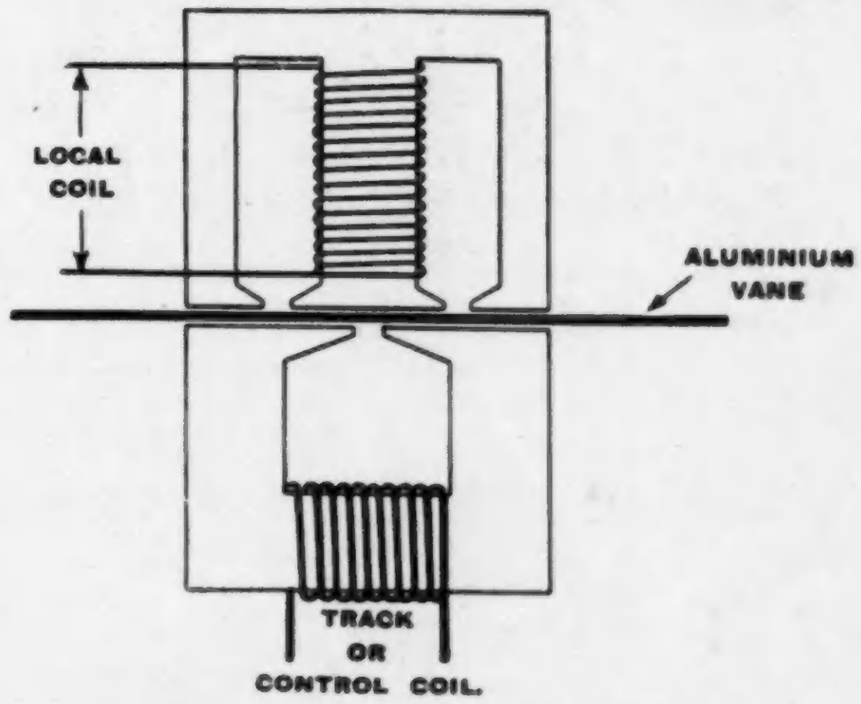



Fig. 6.—Field system of 2-element relay.

arranged in such a way that not only are the correct values of current required to cause the vane to move, but the phase relationship between the currents in the two windings must be within prescribed limits. The field system of a two element relay is shown in fig. 6.

Such an arrangement permits the major portion of the energy required to be supplied from a local source and at a higher pressure, thus necessitating only a

comparatively small amount of energy to be derived from the track circuit at low voltage. In this way much longer track circuits can be operated, as the loss in ballast leakage is reduced to a minimum. Regulation of the phase angle is effected at the feed end of the track circuit by means of the current limiting device, resistance, condenser or impedance coil, as the case may be, and the ideal phase relationship for the type of relay under consideration is 90° between local and track winding currents.

Fig. 7.—Double element A.C. track relay.

Operating figures for a typical double element track relay (one of which is illustrated in fig 7), having four front and two back contacts at 50 cycles are as follows :—

| | Volts. | Amp. | Watts. |
|---|---|---|---|
| Local Coil .. | 110 | 0.35 | 11.0 |
| Track Coil .. | 0.75 | 0.150 | 0.05 |

(Phase displacement between local and track currents 90°).

It will be noticed that less than 0.5 per cent of the total energy required by the relay is supplied from the track circuit.

TRANSFORMERS.—Core or shell type transformers are employed, air-cooled and provided with tappings. It is permissible to feed two or more track circuits from one transformer, but it is advisable to have separate secondary windings for each track circuit to prevent interference between one track circuit and another fed from the same transformer.

CONDENSERS.—Condensers are usually of the Mansbridge type, oil immersed, and insulated to withstand the maximum traction voltage. The condensers are fitted in sealed, sheet steel cases, and are provided with tappings connected by links to a common bus bar.

IMPEDANCE BONDS.—The core and windings of impedance bonds are housed in a cast iron tank, which rests on lugs or straps attached to the sleepers. The tank is filled with transformer oil or petrolatum to protect the windings and insulations from moisture. A large cast iron cover is bolted on to the tank, and this is "ramped" on all sides to reduce the obstruction to persons walking on the line.

INSULATED JOINTS.—The fish plates at the ends of the track circuits are insulated by tough fibre insulations, the bolts being surrounded by fibre collets, while a fibre end-post of the same shape as the rail section is fitted between the ends of the rails.

All the point rodding and any other metal fittings which have to cross the track must likewise be insulated, but as the track voltage is low, dielectric strength is of secondary importance compared with ability to withstand severe mechanical treatment.

In conclusion it might be added that the theoretical consideration of the alternating current track circuit and its vectorial analysis provides some fascinating problems.

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# Laying the Cairo-Alexandria Trunk Telephone Cable.

**A section of the 130 miles of Pirelli-General cable, containing ninety-two conductors, being laid across the Nile. The whole of the terminating equipment was supplied by the G.E.C. Telephone Works and the loading coils by the G.E.C. Salford Electrical Instrument Works.**

# A Traffic Control Party Line Telephone System
## with Selective Calling by Dial.

By N. C. SMART,
G.E.C. Telephone Works.

*Following the brief study of the A.C. track circuit on p. 24, it is interesting to turn to another important aspect of railway traffic control. Whereas the track circuit automatically affords an indication of the presence of vehicles on running rails and is employed for signalling and controlling traffic locally from signal boxes, the telephone is instrumental in bringing all these points under central control for directing traffic as a whole.*

ONE of the most vital and arduous services which the telephone is called upon to perform is in connection with the control of railway traffic, where it forms the means of communication between the controller and the many signal boxes and other points through which his orders are made effective. This service is especially vital in that the movements of trains within the area served are dependent upon the rapid transmission of orders to the way stations and the accurate receipt of information at the control office. It is especially arduous because of the long distances to be conversed over, and the large number of stations worked on one pair of lines.

The actual routine of the working of traffic control systems varies considerably with different railway companies, and no attempt will be made here to describe the methods employed. It will be sufficient to mention that as trains pass over the section of line under their control, the signalmen must give information as to their movements to the control office which is usually situated at the approximate geographical centre of the system. By means of this information the controller is able to keep up to date some form of log, chart or visible indicator which thus forms a record of train movements. At the way stations, instructions are received from the controller, who is responsible for the smooth running of the system as a whole.

As the points with which communication has to be established are located at intervals along the railway line, and as the distance to the most remote may be considerable, it is not economically possible to run more than one pair of wires along each section for control purposes. The telephone system therefore becomes in effect a group of very large "party lines," each having perhaps 50 stations bridged across a line 60 miles or more in length, the conductors being usually of overhead copper wire weighing between 150 lbs. and 250 lbs. per mile.

In the ordinary public telephone system, party lines are generally worked on the "code call" principle, a bell being connected directly across the lines at each station. To call any party, a code of short and long rings is transmitted to all the bells and is answered only from that station which has been allocated the particular code transmitted. This method is not applicable to the type of system under consideration owing to (1) the impossibility of devising a code of reasonable length and clarity for each of 50 stations or more; (2) the length of time required to send out a long code when time may be a vital factor; (3) the difficulty of manipulating the means for transmitting the code, and (4) the unnecessary ringing of bells at unwanted stations.

From the above a list of the chief requirements of a train control system may be drawn up.

(1) Clear transmission and reception of speech.
(2) A means of calling which shall be simple to use and rapid in operation.
(3) The bell to ring at wanted stations only.
(4) The apparatus employed throughout to be sturdy and reliable.

In the selective ringing system which it is now proposed to describe, these requirements are met in the following manner :—

(1) Special transmitting and receiving circuits and apparatus have been designed to give clear speech over long lines.

(2) The means provided for calling consists of a dial switch as used in public automatic telephone service. This device is convenient and rapid in operation. It has a further advantage in that it occupies a very small space on the controller's desk, thus allowing greater freedom in the disposition of log sheets, charts and other indicators.

(3) At each station a selector is provided which responds to impulses transmitted over the line wires by the manipulation of the dial at the control office. Only if this selector is set in the position peculiar to the station at which it is located is the call bell at that station rung.

(4) The apparatus consists of relays and rotary selectors of the types used in automatic telephone systems where their reliability has been proved in public service.

It has been mentioned that impulses are transmitted over the line wires to position selectors at all stations. As the accuracy of calling depends upon the accuracy of the transmission and reception of these impulses, special measures are taken to ensure satisfactory impulsing over the exceptionally long lines peculiar to train control systems. In automatic telephony signalling is accomplished by means of interruptions in the line current. This method* is simple and efficient if the line resistances and capacities are of reasonably low values, but is unsuitable where high resistances and capacities are encountered. The principle of reverse current impulsing is therefore employed.

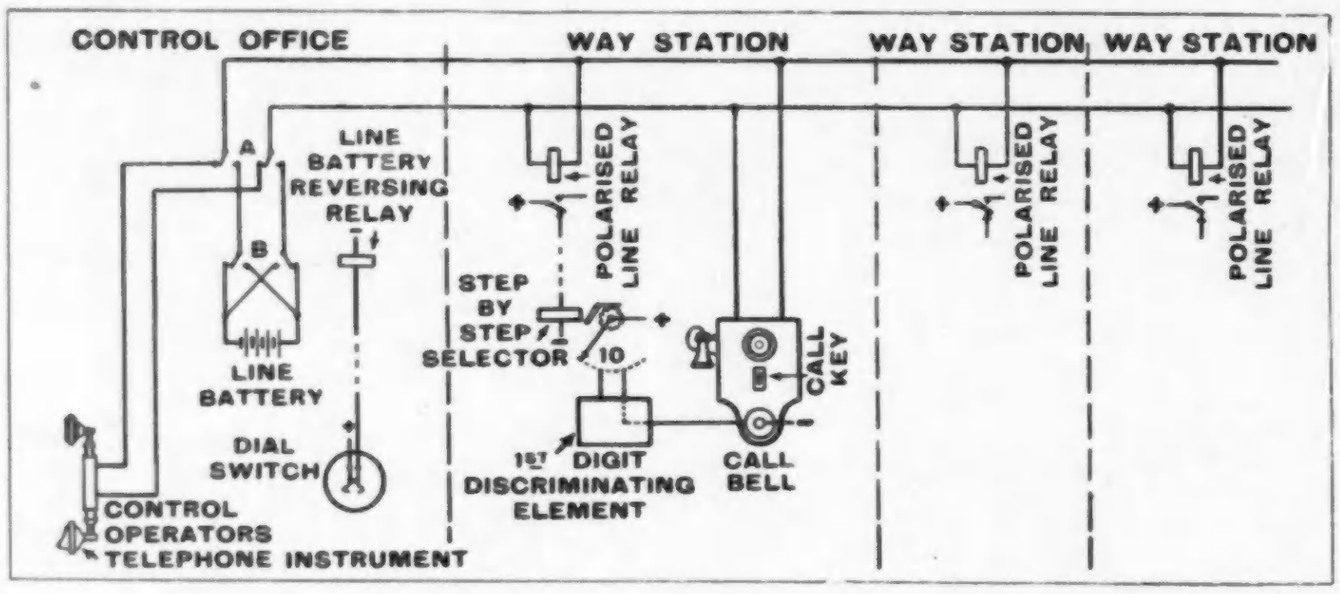



**Fig. 1.—Simplified diagram illustrating method of selection.**

A simplified diagram to show the method of selection is given in fig. 1. In the normal condition the lines at the control office are connected directly to the operator's telephone and also to a local lamp indicator circuit which enables the way stations to signal the controller when he is not listening on the line. When the dial finger plate is rotated in a clockwise direction (preparatory to release on reaching the finger stop), contacts A are operated and automatically locked so that the line battery is placed across the line. Through its impulse springs the dial also controls a relay having contacts B which connect the line battery in a direction, depending on whether this relay is operated or released. Thus when the dial finger plate is released, the direct current flowing in the line is interrupted and reversed a number of times according to the digit dialled.

At each way station there is bridged across the lines a polarized relay which operates to the current received before impulsing begins, and releases at each reversal, *i.e.*, when the dial impulse springs open. The contacts of this relay therefore reproduce the functioning of the operator's dial.

The impulses are received at all way stations and control the stepping of a rotary selector of the type illustrated in fig. 2. This selector is capable of being set in any one of ten positions, but as the number of stations on a line greatly exceeds this figure, it becomes necessary to transmit two trains of impulses to obtain selection over the desired range. The stations are accordingly considered in groups, the first, or "tens," digit selecting the particular group required, and the second, or "units," digit the particular station in that group. Actually there may be ten groups of nine stations each, the system having a capacity of 90 stations on one line.

In calling the station numbered 73, for example, the controller will first dial the digit 7 and the selectors at all stations will be stepped up to their seventh position. At all stations having 7 as the first digit of their characteristic number the reception of this digit prepares the local circuit for further discrimination on the second digit. All other stations remain unprepared for this discrimination.

The controller now dials the second digit, in this case 3. This is again received at all stations but is only effective to cause further discrimination at those which were prepared by the first digit 7. The number of such stations is limited to nine and thus the second digit is able to select the particular one required in that group. In this case the station having 3 as its second digit will be selected. At this station only will the circuit conditions be such that the call bell rings. The bell will continue to ring until either the telephone receiver is lifted or the controller disconnects the battery from the line. The latter operation involves the release of contacts A, which have remained locked, and is effected by the depression of a key fitted to the controller's telephone.

It should be noted here that if the receiver is inadvertently left off its hook the station can still be called. The circuit is so arranged that the call bell will ring in the usual manner and may then be silenced by the momentary replacement of the receiver. Thus a safeguard is given against any

*G.E.C. *Journal*, Vol. I., No. 2, p.p. 53-58.—"The Remote Control of Selective Switches in Automatic Telephony."

station being cut off from the controller in such circumstances.

During the whole of the time that the call bell is ringing a tone is superimposed on the line and reaches the controller's telephone receiver through a transformer which forms part of an auxiliary circuit connected to the line at the control office during the calling period. As this tone is actually generated by the vibrations of the armature of the bell, its reception is a positive indication that the bell is ringing.

When the ringing tone ceases the wanted station has answered, and the controller thereupon disconnects the battery from the line in the manner already stated. This restores to normal the selectors at all stations, and conversation can proceed.

In addition to the selection of any one of a large number of stations, a further facility given by this system is that known as the "common call." This allows the controller, by the dialling of a special number consisting of one digit only, simultaneously to call all the stations on one control line. When this digit is dialled, the selectors at all stations are advanced to a position in which the call bells are rung immediately. Ringing tone is fed to the line from each station, where the circuit conditions are now such that on lifting the receiver the call bell is not silenced. This indicates to the attendant that a common call is being made and prevents the confusion caused by a number of stations coming on to the line together and simultaneously announcing their identity. Although the call bells continue to ring, the ringing tone is cut off at each station as the receiver is lifted, until finally, when the last station answers, the tone ceases entirely. The controller is therefore given a definite indication that all station attendants are listening on the line, and he then disconnects the line battery to silence the bells. This service is commonly required for the communication of general instructions, time signals, etc., its value depending largely on the time taken to verify that every station has answered. When compared with the usual roll call the method employed in the system under review is infinitely more rapid and accurate.

If the controller is provided with a receiver of the headset type he can listen continuously on the line, and a distant party desiring to communicate with him need only lift the way station receiver and speak. Such head receivers are, however, rather irksome to wear and since they also restrict the movements of the user, a hand combination type of telephone is often preferred. The controller does not then listen continuously and it becomes necessary to provide a means of calling him. Each way station instrument is therefore equipped with a key which, when depressed, connects a small local battery across the line, operating at the control office a sensitive relay which lights a calling lamp on the control desk. This signalling circuit is so arranged that the relay remains operated and the calling lamp glows until the controller answers, although the key at the way station is only momentarily depressed.

In many instances it is found that there are occasions when connection is desired between the control office and points which are not normally of sufficient importance to justify their being served by the main control telephone system. They may, for example, be signal boxes on a branch line of

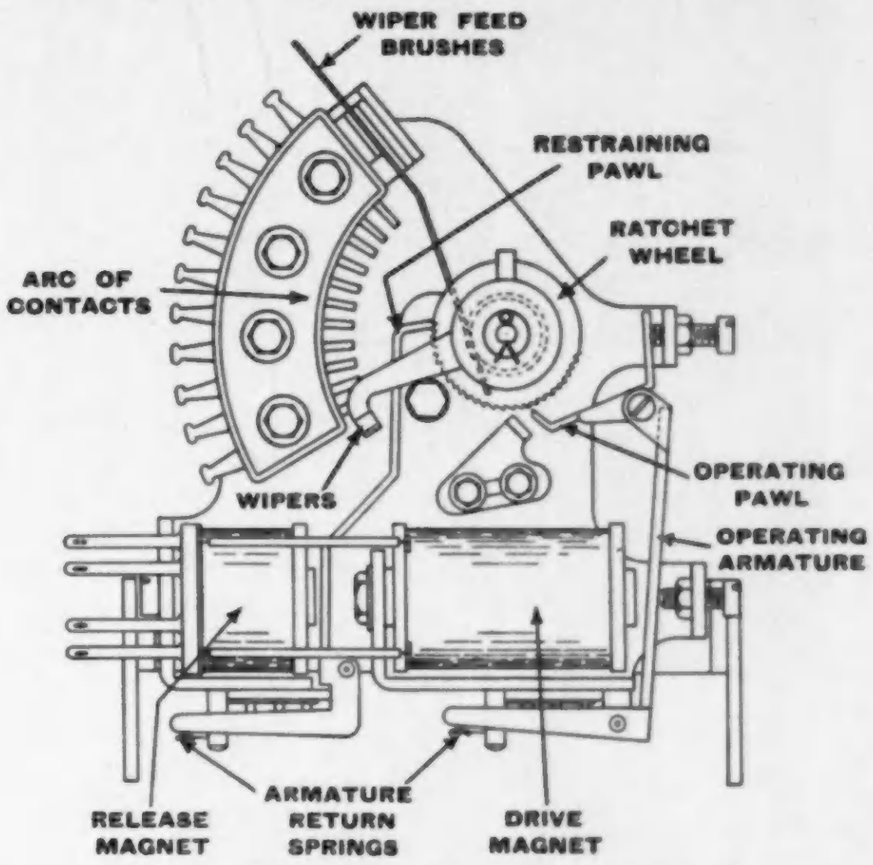



Fig. 2.—Rotary step-by-step selector.

the railway carrying only light traffic. Such points are usually served by a local code ringing system employing the better known type of railway telephone equipped with a relay to close the call bell circuit, and a calling key by means of which a code of short and long rings may be sent out to all stations.

With the dial calling system under consideration a unique device is introduced for the automatic connection of local code ringing lines so that they may be worked when required from the controller's desk. At that station on the control line which forms the junction point with the branch line, an auxiliary equipment called a code ringing repeater is provided, which, when a particular number is dialled by the controller, functions to couple the two lines together. Further impulsing by the controller results in the local battery at this station being applied to the code ringing line continuously during the reception of each train of impulses. The dialling speed being ten impulses per second, the reception of digit "0" will cause the battery to be connected to the line for a period of one second, and digit "3" for approximately one third of a second. The relays at all stations will respond

accordingly and the duration of the ringing of the bells will thus depend on the digit dialled.

To call any station on a local line where this facility of interconnection is provided, the controller first dials the particular two digits allocated to the code ringing repeater and so automatically couples up the main control line. The digits 0 and 3 are then dialled according to the code of the wanted station.

**Fig. 3.—Control office transmitting unit.**

For example, if the code is "long-short-long," the digits will be 030. The bells at all stations on the local line will give out this selected code which may then be repeated by the dialling of the same three digits until the wanted station replies. After the conversation has ended, the uncoupling of the lines is effected by the dialling of one digit allocated for this purpose. At the control office the calling codes of all local line stations will therefore consist of three parts such as 59–030–5, 59 being the coupling code, 030 the station ringing code, and 5 the uncoupling digit.

By means of the code ringing repeater it is also possible for stations on local lines to call the control office. As an addition to the local telephone instrument a key may be provided which, when operated, causes the code ringing line to be coupled to the main control system as before. Without any further action by the attendant, conversation can then be carried on if the controller is listening continuously on the line. If, however, no reply is received from the controller, the attendant will operate the ordinary calling key once, causing the code ringing repeater to apply the calling battery to the control line, and so light the lamp on the control desk. At the same time depression of the calling key will ring the bells once at all local stations, but this signal will be ignored since it will not constitute a station code call. On completion of the conversation the lines are uncoupled by the attendant at the local station again operating the coupling key.

Where several control lines are worked from one office, each requiring an operator's undivided attention during normal traffic periods only, it is the usual practice at other times to concentrate two or more lines on one position of the control desk. To provide for this the lines are not definitely terminated on any one position, but are connected to coupling keys which appear on all positions. A controller coming on duty is therefore required to operate the coupling key associated with the line which he works and so connect his telephone and calling equipment to that line. Incoming signals will then be received on his position until the coupling key is restored when they will appear on the master position.

Such methods of distribution and concentration of lines in the control office are naturally dependent on the routine adopted and vary considerably with different transport undertakings. In the following more detailed description of the apparatus employed it is therefore proposed to deal with the various units without reference to the variety of internal switching arrangements which may be introduced to meet specific requirements.

## CONTROL OFFICE EQUIPMENT.

The equipment provided at a control office may be divided into four groups, namely :

(*a*) A dial, with coupling key and lamp cabinet, per position.
(*b*) A transmitting unit per line circuit.
(*c*) An operator's telephone set per position.
(*d*) Signalling and speaking batteries.

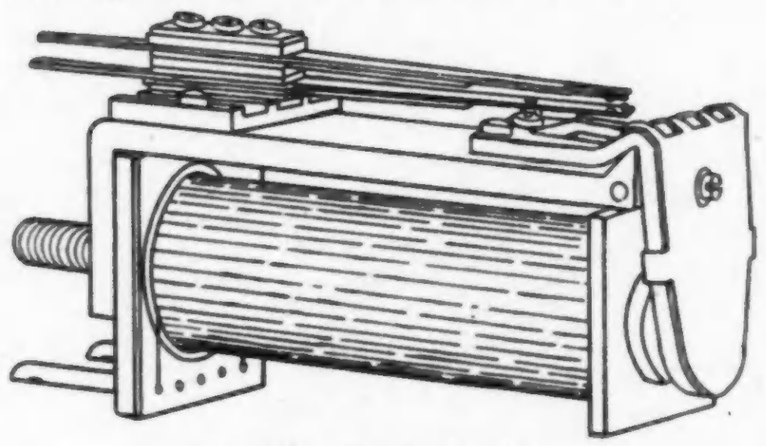


**Fig. 4.—Typical relay.**

### (a) THE DIAL, COUPLING KEY AND LAMP CABINET.

The location of the equipment on the control positions is a matter of choice and there are several popular methods of assembling the apparatus for the convenience of the user. It may, for example, be contained in a small, compact cabinet complete with local wiring and terminals ready for cabling to the external parts of the circuit. The key and lamp panel is hinged in the face of the cabinet to provide ready access to the wiring, the dial being connected by means of a jack-in type mounting which permits

instant replacement of the calling device without disturbing the permanent wiring.

As an alternative, the dial, keys and lamps may be mounted on a panel framework arranged for insertion in the flat writing top of the control desk.

A third method, which has recently been adopted by a leading British railway company, includes the provision of a special panel with both horizontal and vertical faces, the former being equipped with the coupling keys which line up with the writing top of the desk, and the latter forming the lamp panel which is mounted flush with the back rail. In this case the dial is fitted in a separate jack-in type mounting at the front of the desk.

### (b) THE TRANSMITTING UNIT.

The transmitting unit is illustrated in fig. 3 and consists of a group of relays, impulse smoothing equipment, line protectors, line cut-off switches, battery fuses and a battery cut-off switch, all mounted on a teak backboard with a hinged cover for those parts not having individual protection. The relays are of the types used in automatic telephone exchanges and are fitted with springs having double platinum contacts (fig. 4).

The impulse smoothing equipment comprises two retardation coils with condenser and resistances forming a filter in the dialling circuit. This serves to smoothen the line impulses, to reduce sparking at the contacts of the impulsing relay, and also to reduce interference with adjacent lines during dialling.

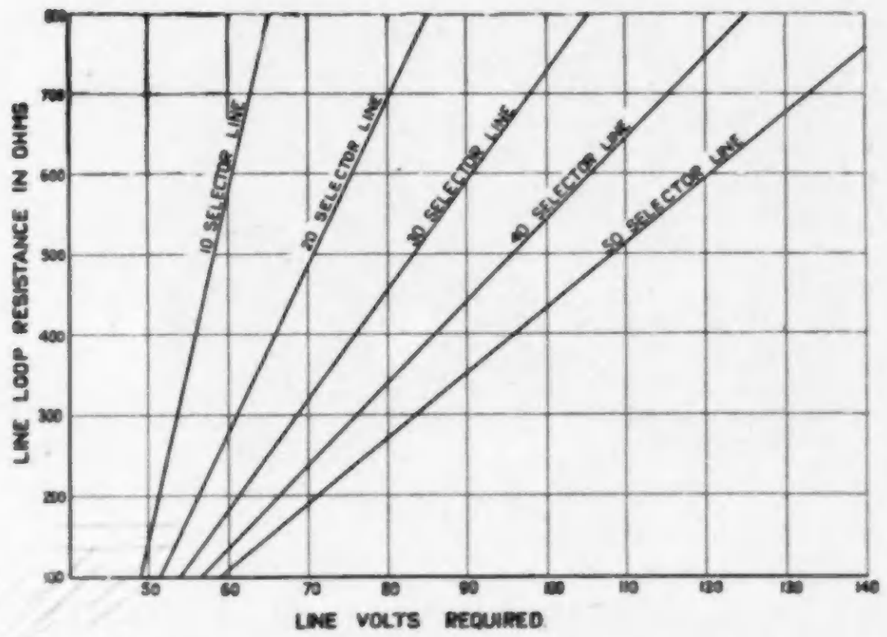



**Fig. 5.—Illustrating relationship between line loop resistance and line volts required.**

Two line protectors are provided, each consisting of two fuses of the glass tube type, two heat coils and two lightning arresters, assembled on a porcelain base with common cover. This duplication is to allow the connection of two lines serving different sections of the railway system but which may be operated together as one circuit with a common numbering scheme, thus requiring only one transmitting unit.

### (c) THE OPERATOR'S TELEPHONE SET.

Where the controller listens continuously on the line his telephone comprises a standard head receiver and a transmitter which may be either of the breast-plate or pedestal type. A foot-switch is also provided for disconnecting the battery from the line after calling a way station, and for completing the transmitter circuit. The alternative instrument, for use when way stations are required to signal the

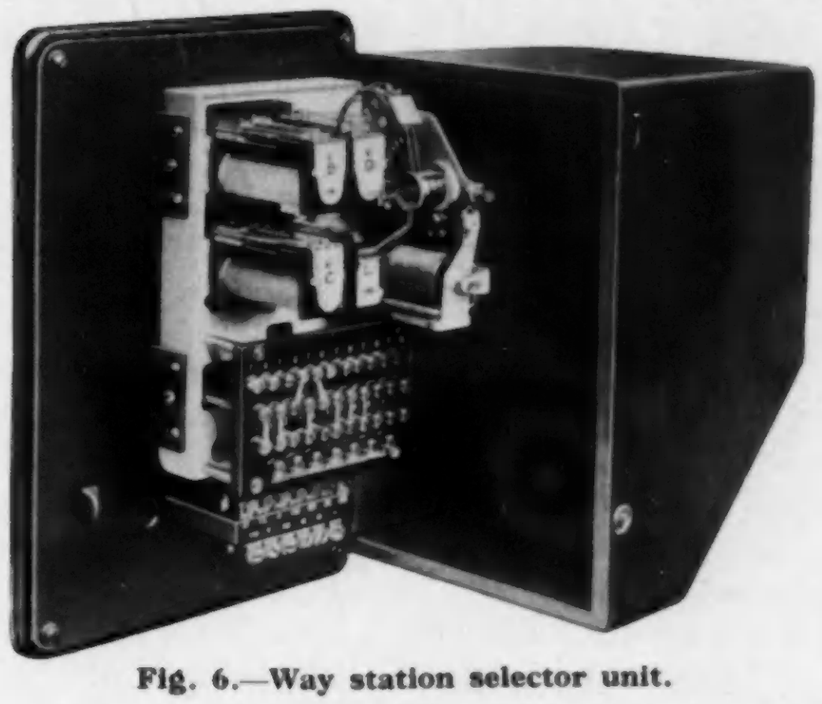


**Fig. 6.—Way station selector unit.**

controller, is the ordinary hand-combination set in which the press key takes the place of the foot-switch.

### (d) SIGNALLING AND SPEAKING BATTERIES.

As shown in fig. 5, the voltage of the main battery for the supply of line current for signalling depends on the number of way stations served by a line and the resistance of the line loop. From this battery a 50-volt tapping is taken for the relay circuits in the control office, the transmitter current being obtained from a separate source.

## WAY STATION EQUIPMENT.

The equipment at each way station consists of:
(*a*) A selector unit. (*b*) A telephone instrument.
(*c*) A line protector. (*d*) Two batteries.

### (c) THE SELECTOR UNIT.

The selector unit is illustrated in fig. 6 and will be seen to include the rotary step-by-step selector, a group of four relays, a cross-connecting panel and a variable resistance mounted on a teak backboard with cover.

The selector (shown in fig. 2) is of a type extensively used in automatic telephony and is unaffected by gravity, vibration or dust. It consists of an arc of contacts swept by a set of "wipers" or brushes clamped to a shaft carrying a ratchet wheel which is engaged by the operating pawl. This pawl is pivoted on the extremity of the operating armature which is pulled forward under the control of the drive magnet against the tension of the return spring. The restraining pawl is kept in engagement with the ratchet wheel by a spring, and is pulled

out of engagement when the release magnet is energised. The return spring is housed within the hollow ratchet wheel and having one extremity clamped to the ratchet and the other to the frame,

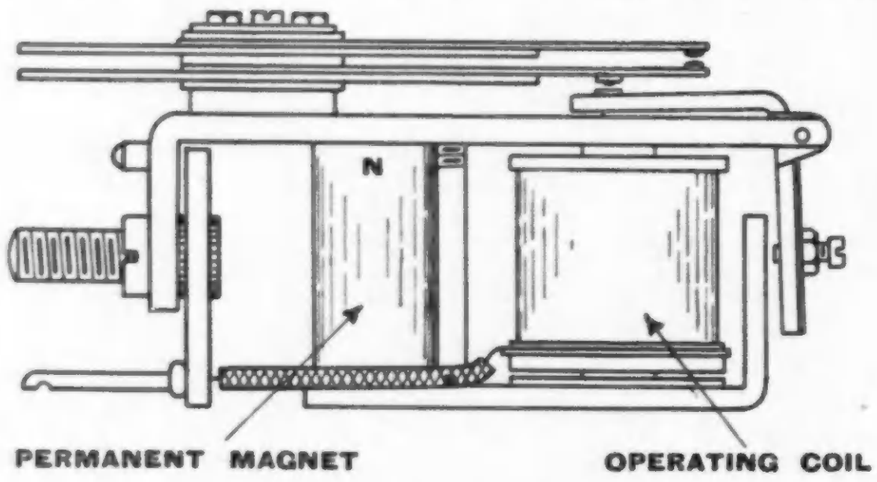



**Fig. 7.—Polarized line relay.**

is wound up as the wipers are advanced over the arc of contacts. When the restraining pawl is withdrawn from the ratchet this spring returns the wipers to a normal position.

The polarized line relay by which the dialled impulses are received is shown in fig. 7. When its coil is energized to have a similar polarity to the permanent magnet the armature is attracted and the contacts operated. With each reversal of the line battery during impulsing, the coil is energized

**Fig. 8 (Above).—Way station telephone (wall pattern).**

**Fig. 9 (Right).—Code ringing repeater.**

so that its polarity is reversed, and as the flux across the armature gap is decreased owing to the shunt path provided by the permanent magnet, the armature is released.

By means of the links on the cross-connecting panel the selector may readily be arranged to respond to a particular code. If, for example, the number of the station at which the selector unit is installed is 53, the corresponding "tens" and "units" terminals are linked to their respective points. The advantage of this device is in the consequent standardization of all way station equipment and the simplicity with which numbering schemes may be revised or altered in the event of extensions being made to the system.

The variable compensating resistance group is placed in series with the line relay and is provided so that suitable settings may be made at each station to give approximately equal currents in all line relays.

### (b) THE TELEPHONE INSTRUMENTS.

A typical wall pattern telephone is shown in fig. 8. In general design this instrument follows standard practice and is equipped with a ringing key for calling the control office. A second key may also be fitted for connecting the transmitter circuit and simultaneously placing a shunt across the receiver in order to increase the transmission efficiency over long and heavily loaded lines.

### (c) THE LINE PROTECTOR.

The line protector unit contains the usual fuses, heat coils and lightning arresters and is identical with that fitted on the control office transmitting unit. At the way station it forms a separate item for installation with similar devices serving telegraph and other circuits entering the station together.

### (d) BATTERIES.

For the selector, relay, signalling and bell circuits at each way station, one 12-volt battery is required, which may consist of high capacity primary cells. A separate three-cell battery is employed for the local transmitter circuit.

### CODE RINGING REPEATER.

The additional equipment for the way station which forms the point of junction between the main system and a local code ringing line consists only of a group of nine relays suitably mounted and wired for connection to appropriate points on the selector unit. An illustration of the complete code ringing repeater is given in fig. 9.

# The Mass Production of Incandescent Electric Lamps.

*(Continued).*

By G. CHELIOTI

Works Manager, Osram-G.E.C. Lamp Works.

## GENERAL OPERATION OF THE FACTORY.

THE conditions which were outlined in the section of this article headed "Limitations" (*G.E.C. Journal*, Vol. 1, No. 4, page 176) evidently fall far short of the "single type" ideal which would permit the steady inflow of uniform supplies of material for immediate use and the prompt evacuation of the product into outside channels of distribution to the user; it was consequently necessary in planning the factory to ear-mark no less than two-thirds of the total floor space for storage. The building was therefore designed with three floors, each 400 feet long by 80 feet wide, the topmost to be occupied by the manufacturing plant, the middle by the finished lamps (in standard packages of 50 to 100 according to size), and the ground floor by the raw materials (fig. 7). This arrangement has several advantages; all the processes are performed on the top floor, (fig. 8), where ample light and air are available, and materials can be raised once for all by mechanical means from ground level to top floor, gravity being used to transport the finished goods from factory to store, and again from store to ground level for despatch.

The sub-division of the entire process of fabrication of an electric lamp from primary raw materials has been dealt with previously; we are now concerned with what happens after the component parts of the lamp have all been brought together in the stores of the assembling factory. Reference to fig. 7 will show the general disposition of these materials in the ground floor store rooms. To facilitate reception, several very large doors enable fully loaded lorries to be driven right into the stores if necessary, while a siding permits the unloading of railway trucks at any one of the

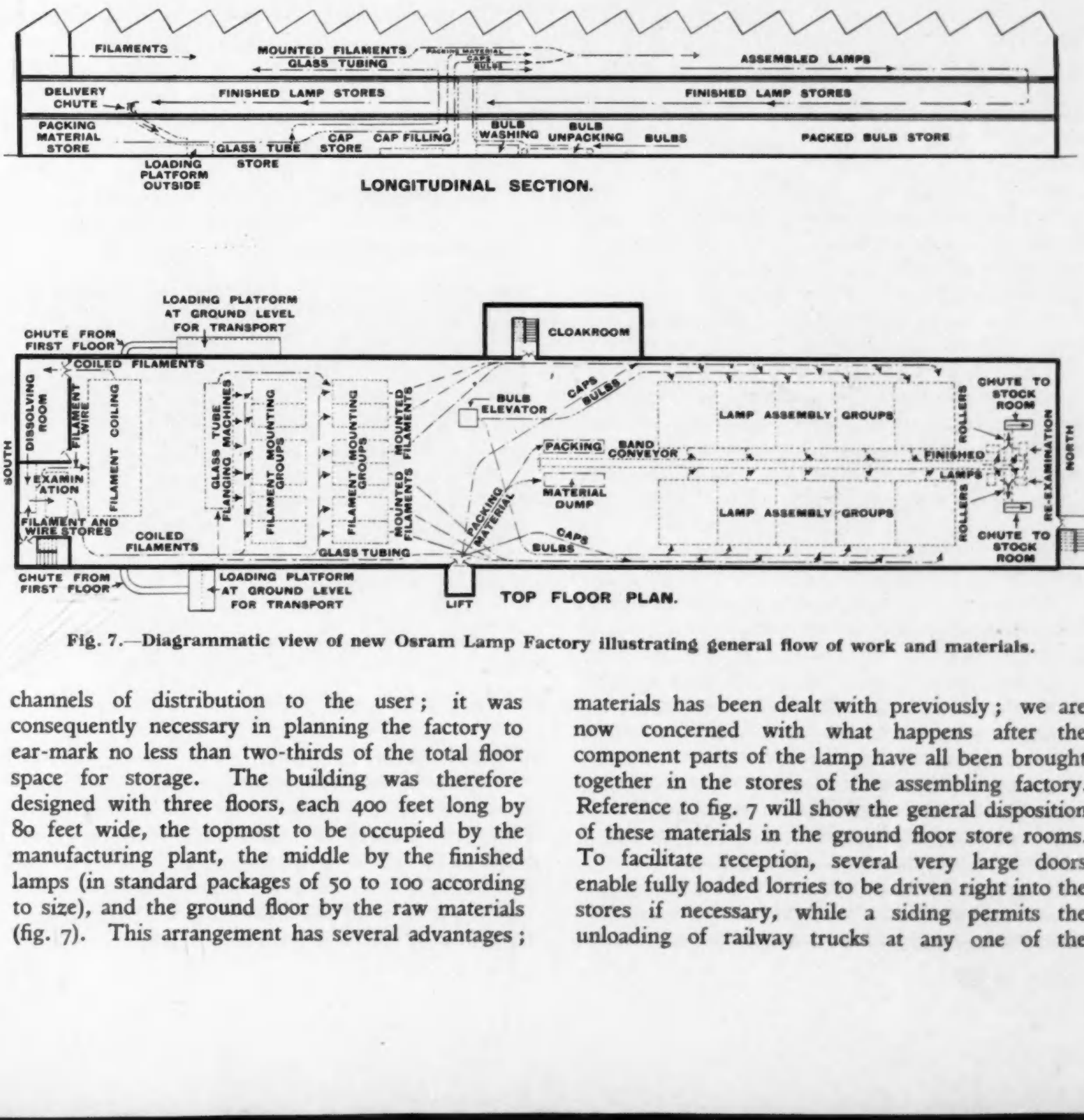



**Fig. 7.—Diagrammatic view of new Osram Lamp Factory illustrating general flow of work and materials.**

corresponding doors on the other side of the building. It has already been pointed out that the imperfect standardization of the product is reflected in the raw materials which, instead of flowing smoothly into the main stream of assembly, must be marshalled in the stores, according to kind and pattern, until the programme of production calls

**Fig. 8.—General view of Assembly Shop (from the North).**

for their issue (fig. 9). The loss of efficiency due to this necessary pause and re-handling has been minimised as far as possible by the introduction of mechanical methods. Besides ordinary gravity roller conveyors, which are freely used, battery-driven electric trucks are employed for shifting the heavier goods. These useful little vehicles are of the "jacking" type, and can bodily lift up and transport loads up to two tons. To obtain the full advantage of this system, the goods are stored on platforms or in skips, so designed as to allow the chassis of the truck to run under and raise them clear of the floor. A lift capable of carrying truck and load together to the upper floors is provided, and a good instance of the economy of the method, when the movement of goods must perforce be intermittent rather than continuous, may be found in the case of glass tubing. This material, made in the neighbouring Glass Works, is piled in bundles on suitable platforms immediately after manufacture. An electric truck picks up the platforms, runs them along some hundreds of yards of roadway and "dumps" them in the stores. When they are required, the truck picks them up again and takes them by the lift to the top floor, depositing them conveniently for their contents to be fed to the appropriate machines, one load sufficing for the manufacture of about 250,000 lamps.

The lamp bulbs are naturally by far the lightest and bulkiest of all the materials, and very special arrangements have been evolved to deal with them. They are made in the Glass Works by machines with individual outputs approaching 100,000 of one pattern per day, an output which so hopelessly outruns the present-day possibilities of consumption that very large stocks must be accumulated in order to permit the machines that continuity of operation for at least a few weeks which is essential to their efficiency. After careful study, the conclusion was reluctantly accepted that no system of continuous mechanical conveyance could be justified: merely to deliver the bulbs to a given point in the stores was insufficient, as it would still leave them to be marshalled into the proper bays, while a plant capable of delivering over a large area would have been extremely costly, besides occupying a great deal of space. The present practice is therefore to pack the bulbs in cardboard boxes, and to load them at the Glass Works on to light hand-trucks (carrying about 4,000 bulbs) on which they are wheeled direct to the proper place in the Lamp Works stores, the whole distance averaging about 200 feet.

The necessary washing before the bulbs are used is performed in the Wembley factory by a machine specially designed to work in conjunction with an

**Fig. 9.—Material Stores (from the South).**

automatic chain elevator, so as to become in effect an integral part of the general transporting mechanism of the factory. The bulbs are unpacked from the original containers in which they are received from the Glass Works, and placed neck-down in galvanized iron wire trays each holding 70 bulbs, but instead of being placed on a simple transporter, the full trays are fed into the washing

machine (fig. 10). Thereafter, without further handling, they are washed with dilute acid, twice rinsed with nearly boiling water, dried by hot air, carried up to the top floor and automatically unloaded on to a roller track, whence an attendant transfers them to wheeled cages. As each cage carries over 1,000 bulbs, the handling unit is again fairly large, but it may be noted once more that perfect standardization of the product would have made it possible to use a continuous conveyor system instead of these units, which, of course, are necessary in order to secure the supply to each machine of the particular type of bulb it needs. The caps are the only components besides bulbs which undergo any process before arrival in the assembly shop: it is convenient to intercept them before they leave the stores, unpack them, fill them mechanically with the proper amount of cement for attachment to the bulbs and place them in piled trays to be handled in bulk by the electric trucks. The conveyance of the remainder of the materials to the working floor presents no special problem; packing materials (which are fairly heavy when folded flat) are handled by electric trucks, but there is nothing else of great bulk or weight.

The top storey of the building, in which the real work of the factory is carried out, is a single,

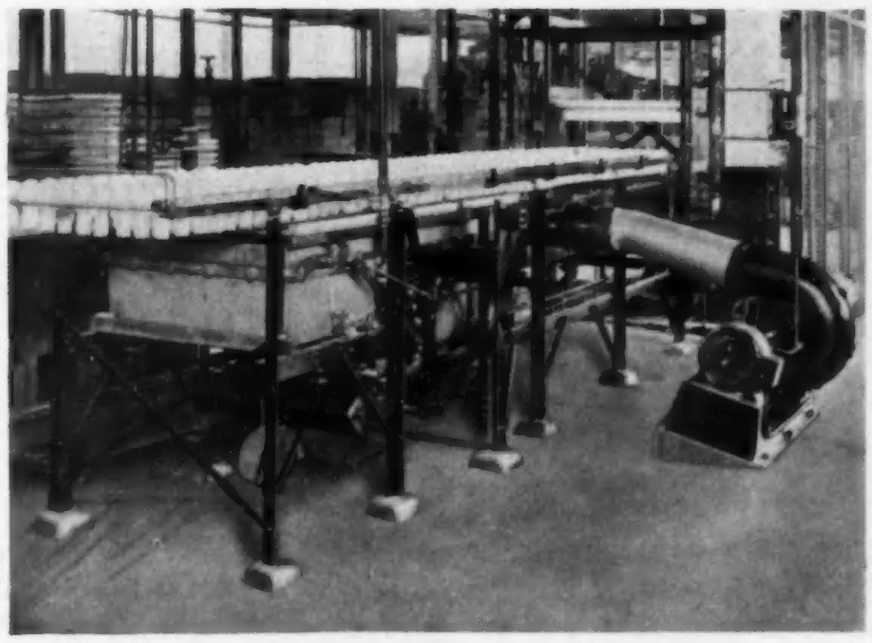


**Fig. 10.—Machine for washing and drying bulbs.**

rectangular room of 32,000 square feet, and its lofty north-light roof gives it a capacity of over 600,000 cubic feet. With one small exception, it has no party walls, no roof-supporting columns, and no other obstructions of any kind, so that it was possible to plan the layout of the plant with entire freedom from the restrictions which are usually imposed by the structural design of a factory building. The plan, fig. 7, gives a general idea of the arrangement, and shows that roughly half of the room is devoted to the phase of assembly which begins with the filament wire and culminates in the mounting of the coiled filaments on their glass "feet." The flow of work during this phase is straightforward except for a short retrogression of the coiled filaments for removal of their steel cores by acid treatment in the

**Fig. 11.—Delivery end of main conveyor belt and final viewing.**

"dissolving room" shown in the plan. The glazed partition which encloses this room to facilitate forced ventilation is the only exception to the rule of "no dividing walls." In all stages of lamp assembly, the parts handled are individually very light and inclined to bulk, but here, as the protecting bulbs have not yet been added, there are the complications of extreme fragility and liability to accidental damage. The aim, therefore, is to minimise the number and length of transportations of parts in a tender state. The machines which build up the glass "feet" adjoin those which insert the delicate wire supports, delivery being effected automatically along slides, so that the parts come readily to the hand of the operator of the second machine (fig. 6). Thence, arranged in special trays designed to prevent accidental contact, they pass along slides to the operators, seated at an adjacent table, who affix the filaments. Still in the same trays, the completed lamp interiors are enclosed in wheeled cupboards, roughly resembling small bookcases, for transfer to the next series of machines.

Reverting to fig. 7, it will be seen that these machines, which occupy the greater part of the northern half of the room, are arranged in groups like transverse ribs along each side of a longitudinal belt conveyor which represents the backbone in this anatomical simile. Supplied from the gangways which run along each of the side walls, the machines assemble the bulbs, mounted filaments and lamp caps which arrive there by the various means already

described, delivering the finished lamps at the inner ends of the groups, where they meet the packing materials and are made up into standard packages of 50 or 100 lamps, according to size. The belt conveyor, fig 8, performs the double function of distributing the packing materials and collecting the completed packages, delivering the latter to the extreme north end of the room, where they are sealed down, after a final critical examination of a random selection from their contents to check the vigilance of the inspectors who have viewed them in the various stages of manufacture (fig. 11). They then pass by gravity chutes into the finished stock room on the floor below, where they are marshalled, according to type, on platforms adapted for handling by the small non-mechanical jacking trucks which distribute them to the appropriate stock bays

**Fig. 12.—Arrival of finished lamps in lamp stores.**

(fig. 12). The same trucks and platforms are used to collect packages for conveyance to the south end of the stock room, whence they are delivered, again by gravity chutes, to loading platforms for transport by road or rail.

This description will have achieved its purpose if it conveys to the reader that, setting aside those questions of technical control of processes and materials which necessarily loom very large in the fabrication of a product so delicate as an electric lamp, the major problems of organization for mass production centre around storage and transport. No matter how efficient the individual man or machine, overall economy can be attained only by continuity of operation, and the enormous output of modern specialised machinery demands not only very elaborate arrangements for the uninterrupted supply of material, but equally prompt and certain removal of the finished work, if the organism is not to be clogged by its own product. If an army marches—as has been said—"on its stomach," a modern factory certainly depends just as completely on its internal transport.

### DETAILS OF BUILDING AND SERVICES.

The building, 400 feet long by 80 feet wide and running almost exactly north and south, is situated on the North Wembley (Middlesex) estate of The General Electric Company, Ltd. It is of the steel-framed, brick panelled type, with a north-light roof, of which the south slopes are covered with felted steel sheets and lined with plaster board. The upper floors, designed for a load of 2 cwt. per square foot, are of cellular construction, reinforced concrete joists forming a "honeycomb," in which the cells are represented by hollow firebrick blocks. The floors are supported on steel columns spaced 20 feet apart, the manufacturing floor being surfaced with hardwood parquet and the others with granolithic cement. The headroom, clear of roof members, is 16 feet on the top and 14 feet on the lower floors, the content of the main building being approximately 1½ million cubic feet.

As the dimensions just given will suggest, it was intended to make the utmost use of natural light and ventilation, and the results so far are exceedingly satisfactory; though it should be pointed out that the factory has not yet operated at full output in very hot weather. The processes, being of a very delicate nature, require a high degree of illumination, while the use of large amounts of gas in melting the glass parts calls for very free air movement, so that if actual manufacture is carried on in the intermediate floors of a multi-storey building, it must not only be artificially lit even in the daytime, but, if tolerable conditions are to be maintained, it must also be elaborately equipped with costly and obstructive ducts for mechanical ventilation. In the Wembley Lamp Works the working area, besides being wholly covered by the north-light roof, is surrounded on three sides by windows of exceptional size (there is none on the short south wall, thus avoiding excessive heat and glare in sunny weather), and artificial lighting before sunset has been found unnecessary even in very dull weather and for the finest work. Four large ventilating cowls in each of the southerly slopes of roof, capable of renewing the air in the room twelve times per hour in normal conditions, automatically extract the vitiated air which rises freely from below, fresh air being admitted by horizontally hinged window panes, opening along their upper edges so as to minimize draughts by directing the incoming

air upwards. There is a notable absence of those "pockets" of hot and stagnant air which, in factories lacking headroom and direct overhead outlet, often prove almost impossible to disperse even when complex systems of mechanical air circulation are provided.

A particularly interesting feature of the building is the method of roof construction. It was a fundamental requirement of the general scheme that there must be no obstruction whatever in the working space—that is to say, on the top floor—of the factory. Lavatories, lifts, and even staircases were not allowed to break the sacred rectangle, and, consequently, they became mere excrescences on the outline of the main building. The design of a roof to span an 80-foot wide floor without intermediate support was a much more difficult task, and the cost of the building would have been seriously increased had a conventional construction been employed. In such cases, the supporting members are often heavy and costly out of all proportion to the useful work they perform, but in this instance the fact that the roof was to be a roof only, and was not to be used as a support for service pipes, shafting, or any similar additional load, permitted the use of a very strong, yet light and economical design. Without going too deeply into details, it may be said that a series of trusses actually form the northern and southern slopes of the roof, leaning against and supporting one another, without any vertical members or horizontal ties running at right angles to the "valleys" of the roof. This is well shown in the view in fig. 14, taken during the erection of the framework of the building, and it is noticeable since completion that, apart from such obvious advantages as non-interference with lighting fixtures, the absence of the usual overhead network of roof members gives the observer a most agreeable sense of space and freedom. One other unusual detail in the design of the building is that all the floors are cambered, so that any water accidentally spilled—as, for example, through the operation of a sprinkler head—will run to the sides, where suitable outlets are provided for drainage. The difficulty sometimes experienced in such cases—especially when the floor is much encumbered—of removing the water which so obstinately lodges in the shallow depressions always found in "flat" floors, should completely be overcome.

The heating of a building having so great a window area necessitates careful consideration, and in this instance is effected by hot water circulation from four oil-fired boilers housed in a small basement. Radiators are placed under all windows, and hot pipes are liberally distributed under the roof lights to intercept falling currents of cold air, but the system generally is conventional, and calls for no detailed description. The entire building is protected against fire by automatic sprinklers in addition to the usual hydrants, fire buckets and chemical extinctors.

The three-phase, 3,000-volt, electric supply is brought into a sub-station at the extreme north of the ground floor—the position being chosen to allow for the service of future buildings—and is stepped down to 415 volts for internal distribution, direct current for small motors being furnished by two generators driven by synchronous motors designed for a leading power-factor of 0.4. The use of these motors to improve the power-factor of the establishment as a whole has resulted in great economy, thanks to the operation of a power tariff based on kVA maximum demand plus a low charge per B.T.U. A small reciprocating compressor and two turbo-blowers supply air at high and low pressure respectively, the centralised plant for the general service of the factory being completed by a pair of small centrifugal gas boosters. The electric lift, supplied by the Express Lift Co. Ltd., is of the modern type in which a D.C. hoisting motor is fed from a constant-speed motor-generator. Very sensitive and smooth operation is obtained by varying the field current in the D.C. generator and the cage is easily brought to the floor levels with the exactitude required for the passage of heavily loaded electric trucks.

Fig. 13.—Lamp Stores (from the South).

As befits a lamp factory, electric lighting is on modern lines, giving a mean intensity of 12 foot

candles in the working area from 750 watt units hung 18 feet above floor level. It is not yet certain how far it will be necessary to supplement this general illumination by local lighting. Previous experience has always favoured the use of such additional sources of light in certain cases, and it is probably true that the acuity of the operator's vision of very small objects is materially increased by the sharper contrasts of light and shade produced by a relatively small but near source of light. In the new factory, however, the conditions are somewhat unfamiliar; the lighting units are unusually large and are hung unusually high, while there is a complete absence of overhead obstructions, and therefore of fortuitous shadow, so that the requirements in this matter may be considerably altered. For economy in wiring, the main lighting system is served by the same bare conductors which carry the power load, but as a protection against complete darkness in case of a fault causing the breakers to open the power circuit, one lighting unit in every fourth bay is wired directly back to the main switchboard on the ground floor, and so is independent of anything short of a breakdown of the high-tension supply or transformers. In the store rooms for materials and lamps the lighting system is modified, fixed units of 200 or 300 watts illuminating the main gangways and marshalling areas, while portable hand-lamps hung from carriages running freely along stretched overhead wires are provided in the alleyways which intersect the piles of stacked goods.

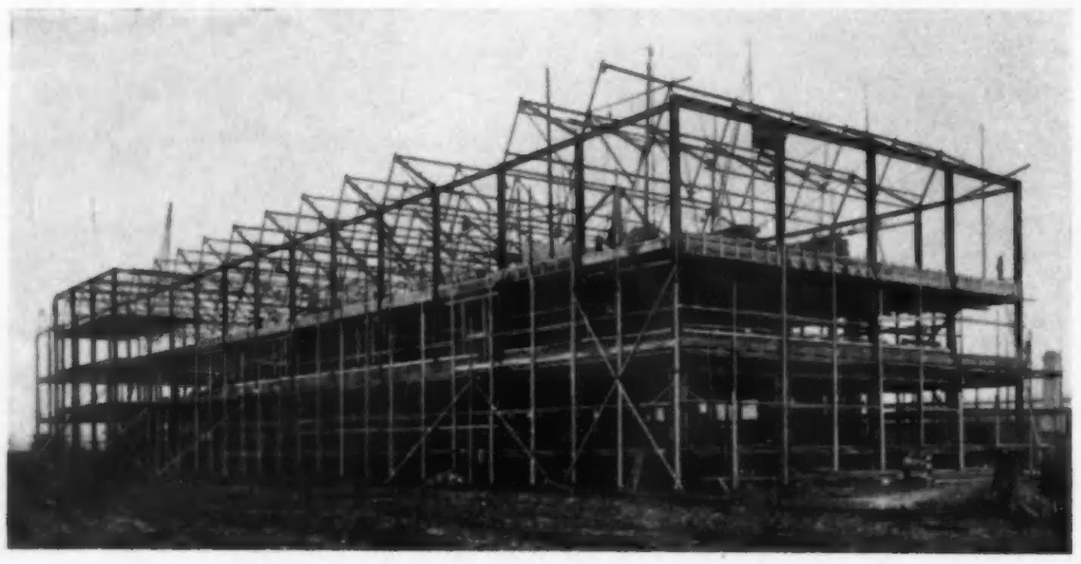


**Fig. 14.—New Lamp Works during erection, showing steel construction.**

The determination to keep clear of obstructions which has already been mentioned was carried to the point of refusal to allow the presence of distribution pipes or electrical conductors above the level of the working floor. This involved the installation of the necessary network *under* that floor, which is to say along the ceiling of the room below—the finished lamp store—down the centre line of which there consequently runs a spinal cord of pipes and conductors. The pipes, carrying gas, air at 4 lbs. and 60 lbs. per sq. in., and fresh and waste water, are branched at frequent intervals, many spare "tees" allowing for possible alterations. There is a departure from conventional lamp factory practice in the absence of main vacuum pipes, small pumps being placed close to the machines they serve on the manufacturing floor. The main conductors are bare copper bars, carried on porcelain insulators and caged in below against accidental contacts; tappings from these bare conductors are, of course, very easily made at any point, ordinary insulated conductors being run thence to feed individual machines. All connections to a given machine, whether of pipes or conductors, are made through a single adjacent hole in the floor, and it should be noted that a cellular floor lends itself admirably to this unceremonious treatment; any one of the firebrick cells may be removed without impairing the strength of the floor, and a very convenient hole some ten inches square is thus afforded.

## THE FUTURE.

What will happen to any industry in the future is a fascinating subject for speculation; will it grow, will it be wiped out by something new, or will it die a natural death? The third is the one inconceivable fate for the electric lamp; until it is supplanted by a better device its use must continue to increase and the means of making it improve. Restlessness seems to be inseparably associated with mass production; those who once become infected with the germ are never content. They find all the excitement of a game in the hunt for means to diminish the input of human effort and increase the output of finished goods, so that their factories are always changing, always trying to catch up with the ideas for improvement which incessantly run ahead of their existing states. This tendency towards change has not been forgotten at Wembley; the very simplicity of the general design of the factory gives it elasticity, and makes it unlikely that any change of method or introduction of novel machinery will render it obsolete. It has been said that the capacity of the factory is 25,000,000 lamps a year, and even if no marked improvement of method arrives to increase it, this could be multiplied four times by using the adjacent land which still lies vacant. Whether or not the future holds the promise of expansion on that vast scale within measurable time, it is hoped that this article has shown that in at least one branch of industry a whole-hearted effort is being made to keep alive the post-war spirit of reconstruction and to refute the charges of backwardness so often hurled against the long-suffering British manufacturer.

# The Mining, Smelting and Refining of Copper in India.

By W. A. Barron, M.Inst.M.M.

Fraser & Chalmers Engineering Works of The General Electric Co., Ltd.

THE fact that India has hitherto occupied a relatively insignificant position among copper producing countries while, at the same time, there are known to be large deposits of copper ore in several of its provinces, lends particular interest to what is actually the only copper smelting and refining plant operating in the country.

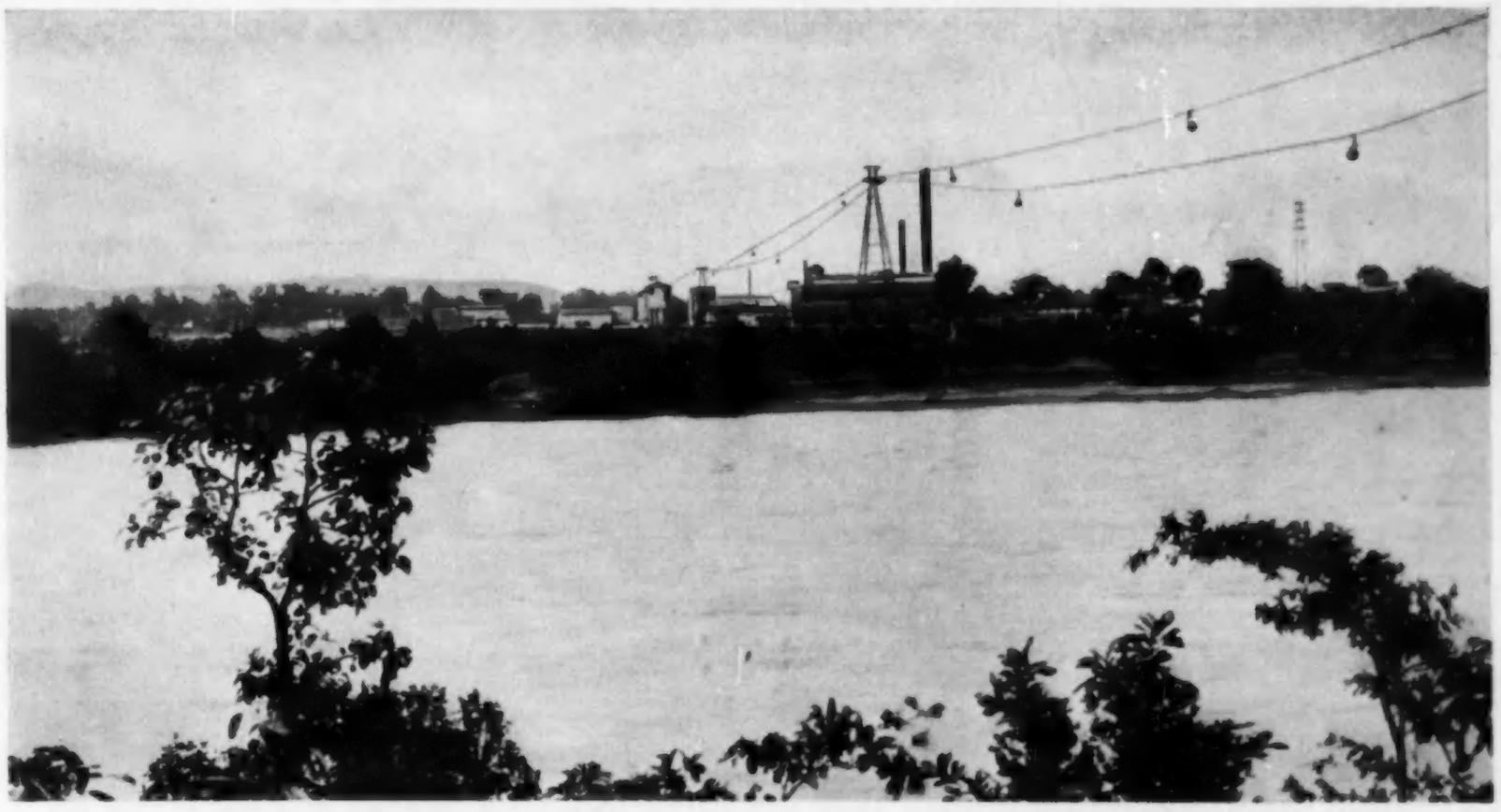


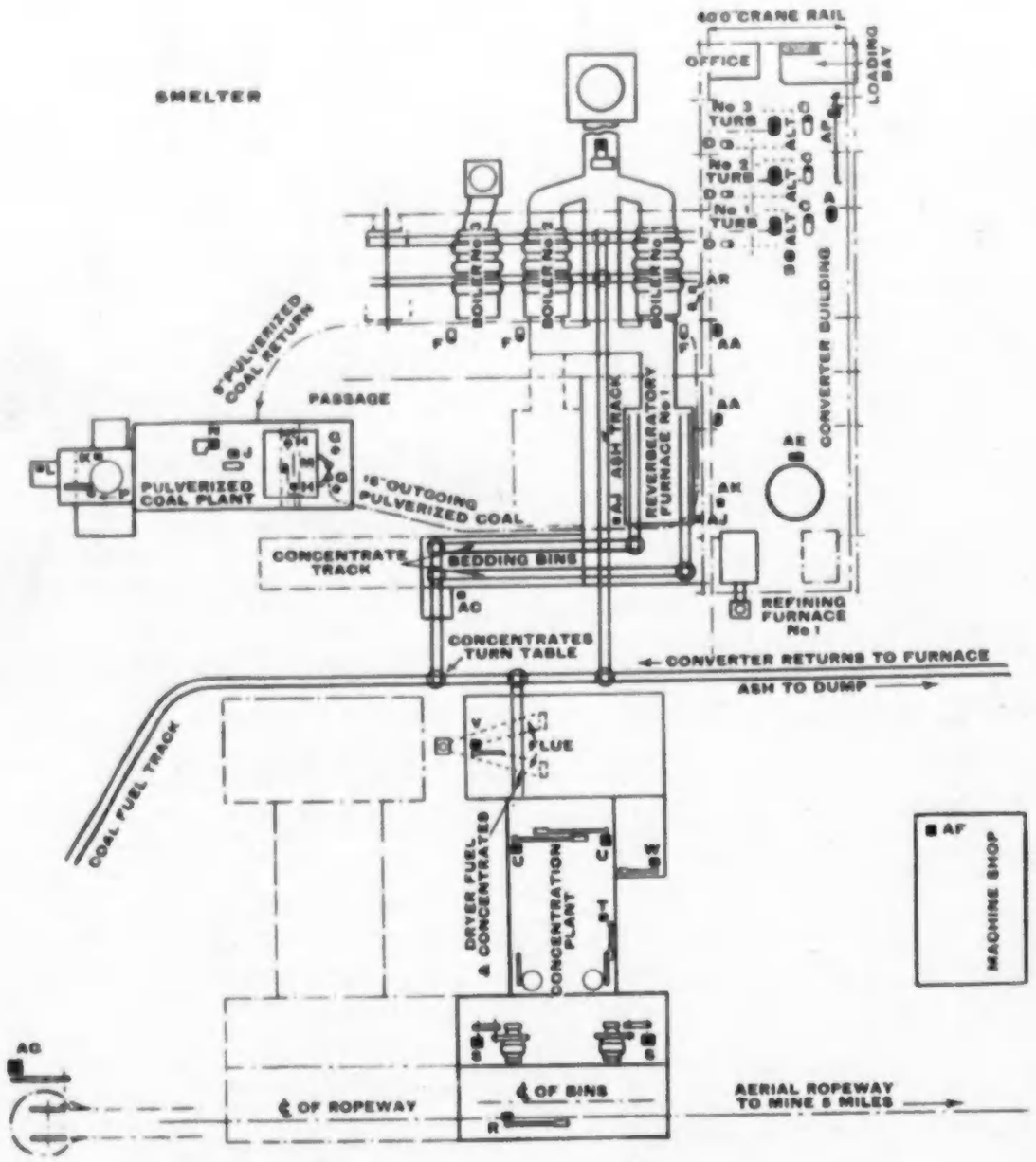
Fig. 1.—General view of Reduction Works from the opposite bank of the Subarnarekha River.

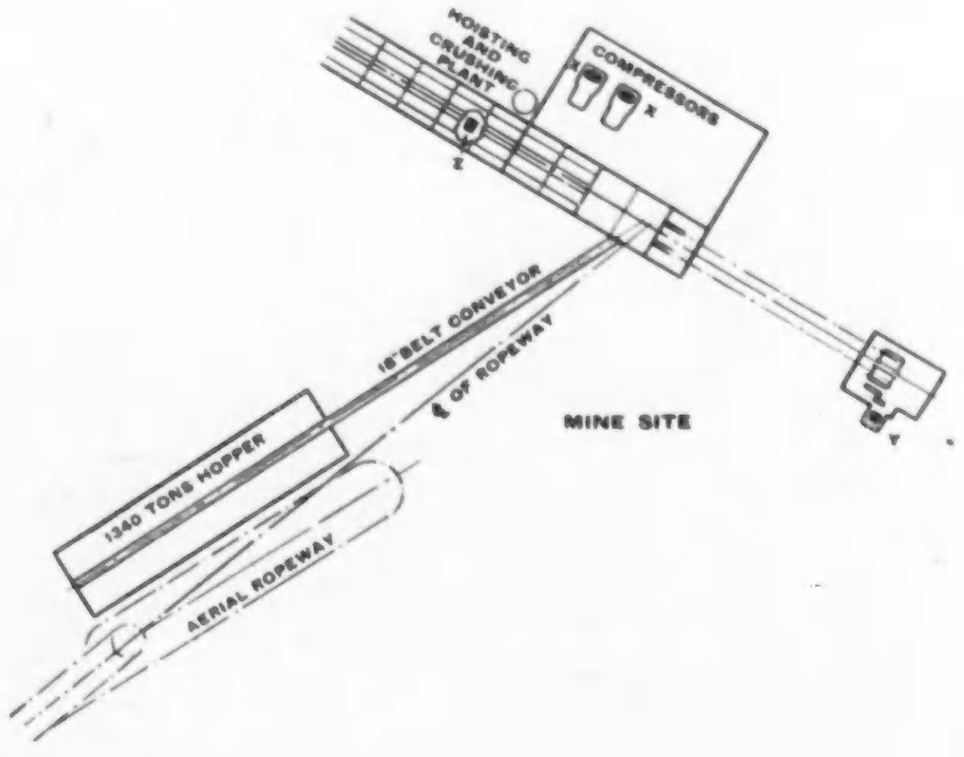
This plant, which is owned by the Indian Copper Corporation, started working early in December, 1928, since when it has been in continuous operation, producing refined copper ingots. More recently, a brass foundry and rolling mill have been added for the production of copper and brass sheets, both of which find a market in India.

The mines and reduction works of the Company are situated in the Singhbhum district of Bengal, Chota Nagpur, about 130 miles from Calcutta, while their mining rights extend over a copper-bearing area of 20 square miles. The company also has the option to purchase mining rights over a further 15 square miles. Mining leases have been granted over 6,900 acres of the area in which the Mosaboni, Dhobani, Surda and other mines are situated. So far, the ore supply has all been taken from the Mosaboni mine which has been in course of development since 1921.

Coarse crushing equipment at the mine prepares the ore for the fine crushing and concentration plant which, with the power house and reduction works, are situated five miles away at Moubhandar, close to the Subarnarekha River and the Bengal and Nagpur Railway. An aerial ropeway, clearly seen in fig. 1, transports the roughly crushed ore from the Mosaboni mine to the reduction works. The site of the power house and reduction works was chosen by reason of its proximity to the railway for transport and to the river for water supply, the bank of the river at this point affording a convenient slope for the disposal of tailings and slag from the treatment plants. A plan of the works showing the arrangement of the building, etc., is shown in fig. 2.

The ores treated are chalcopyrite ($Cu_2S.Fe_2S_3$) and pyrrhotite, containing from 3 to 4 per cent. copper and a little nickel, while the gangue, or matrix, is siliceous and consists chiefly of mica schist.



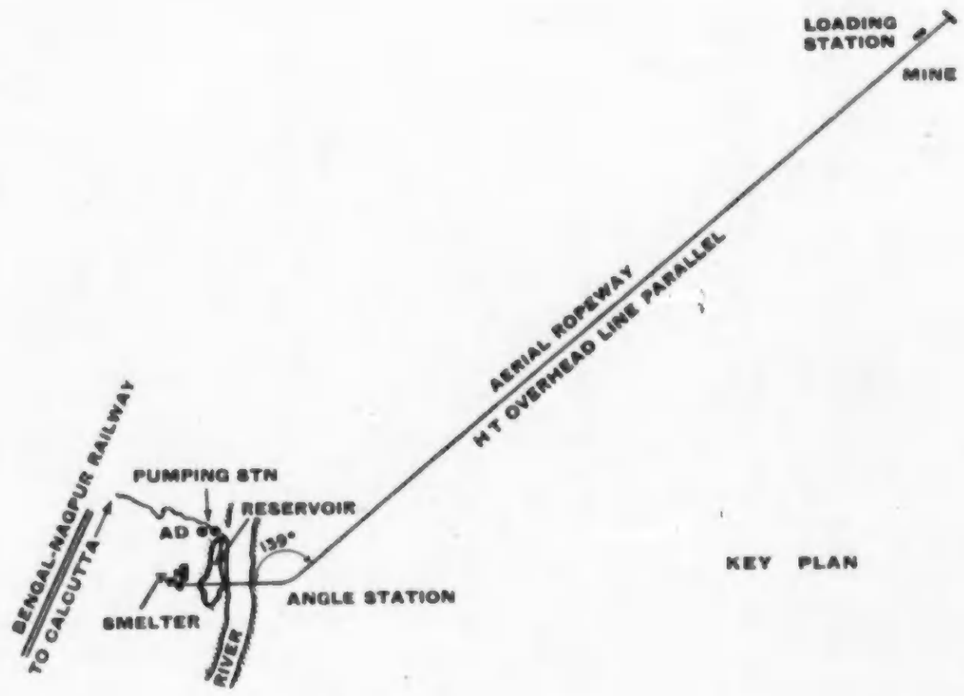




**Fig. 2.—Plan showing arrangement of buildings and disposition of motors, etc.**

## REFERENCE LIST.

| Ref. | No. off. | H.P. | Driving. | Situation. | Ref. | No. off. | H.P. | Driving. | Situation. |
|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 250 | Blower .. . | Power House | X | 2 | 205 | Compressors . | Crushing Plant, Mine |
| B | 1 | 8½ | Generator . | Power House | Y | 1 | 110 | Haulage Gear . | Crushing Plant, Mine |
| C | 3 | 25 | Circ. W. Pumps . | Power House | Z | 1 | 80 | Crushing Plant . | Mine |
| D | 3 | 2 | Condensate Pumps . | Power House | AA | 2 | 15 | Converters .. . | Converter House |
| E | 1 | 25 | I D Fan .. .. | Boiler House | AB | 1 | 10 | Crushed Ore C'veyor | Mine |
| F | 3 | 8 | Hot Secondy. Air Fan | Boiler House | AC | 1 | 14 | Vertical Hoist . | Nr. Bedding Bins |
| G | 2 | 50 | Distributor Fans . | Pulvd. Coal House | AD | 2 | 55 | Vertical Pumps . | River S.S.E. |
| H | 2 | 2½ | Feed Screws (Bin) . | Pulvd. Coal House | AE | 1 | 15 | Casting Wheel . | Converter House |
| J | 1 | 50 | Air Swept Mill Fan . | Pulvd. Coal House | AF | 1 | 25 | Machinery .. . | M/c Shop (Smelter) |
| K | 1 | 10 | Dryer .. . | Pulvd. Coal House | AG | 1 | 70 | Aerial Ropeway . | Concent Ho. N.W. |
| L | 1 | 10 | Coal Crusher . . | Pulvd. Coal House | AH | 2 | 50 | Pumps .. . | Mine |
| M | 1 | ½ | Rotary Air Lock . | Pulvd. Coal House | AJ | 2 | 22 | Secondary Air Fans | Reverberatory Fur. |
| N | 1 | 100 | Ball Mill .. . | Pulvd. Coal House | AK | 1 | 35 | Slag Crusher . . | Converter House |
| P | 1 | 7½ | Elevators .. . | Pulvd. Coal House | AL | — | Total 35 h.p. | Crane . . .. . | Power House |
| R | 1 | 25 | Feeders and Classifiers . | Concentration House | AM | 1 | 8 | Port. Conveyor . | Nr. Bedding Bins |
| S | 2 | 120 | Ball Mill . | Concentration House | AN | 1 | 35 | Machinery .. . | Mine |
| T | 1 | 25 | Steady Hd. Tanks, etc | Concentration House | AP | 1 | 35 kVA | Starting Up .. . | Power House |
| U | 2 | 60 | Mineral Separation . . | Concentration House | AR | 2 | 2½ | Burner-Cooling Centrif. Pumps. . | Boiler House |
| V | 1 | 25 | Dryers .. .. | Concentration House | | | | | |
| W | 1 | 25 | Filtering Equipment | Concentration House | | | | | |

The course of treatment comprises (*a*) crushing and grinding by stages to 60 per cent—200 mesh (*b*) concentration by flotation and the production of a concentrate carrying about 30 per cent. copper, (*c*) smelting the concentrate in a reverberatory furnace to a matte containing about 39.6 per cent. copper, (*d*) bessemerizing in the converter to produce "blister" copper—99.0 per cent. copper, and (*e*) the refining of the blister copper in a reverberatory furnace. The power plant, situated at the reduction works, also provides electric power for the mine through five miles of overhead transmission line. It will thus be seen that the plant is one of considerable size and importance.

The steam generating plant comprises three Stirling water tube boilers, each capable of raising 11,000 lbs. of steam per hour to a pressure of 290 lbs. per sq. inch, superheated and using induced draught. One of the boilers is fired entirely by pulverized coal, and the other two are fired sometimes by pulverized coal but usually by the combustion of the waste gases obtained from the reverberating smelting furnace. A water softening equipment of 630 gallons capacity is also provided.

The Fraser & Chalmers pulverized fuel system installed includes a dryer, a 7ft. by 36in. ball mill for pulverizing, and a pneumatic sizing and distributing system.

**Fig. 3.—Power House showing the three 800 kVA turbo-alternators and the steel plate cubicle switchboard on the left.**

The mining, smelting and refining equipment was supplied by Fraser & Chalmers Engineering Works, and the whole of the electrical plant was manufactured at the Witton Engineering Works of the General Electric Co., Ltd. The consulting engineers to the Indian Copper Corporation for the complete scheme were Messrs. McCarthy & Binns of London.

### POWER HOUSE EQUIPMENT.

The power house (fig. 3) contains three 800 kVA (.8 p.f.) 1,500 r.p.m. open revolving field type alternators driven through gearing by steam turbines running at 6,000 r.p.m. These machines supply current at 420 volts, 3 phase, 50 cycles. Of the total power generated, about 500 h.p. is absorbed at the Mosaboni mine, while the treatment plant at the reduction works including pulverized fuel equipment, aerial ropeway, pumping plant, machine shop and lighting, consumes about 900 h.p. Thus the total power normally required is well within the capacity of two of the turbo-alternators, leaving the third set free as a standby.

For the control of the three alternators and of the nine outgoing feeders, a 12-panel 420 volt steelplate cubicle switchboard is installed (this may be seen to the left of fig. 3), while three floor mounting pillars are provided for controlling the fields of the alternator exciters.

### OVERHEAD LINE FEEDER.

An overhead transmission line conveys power over the five miles between power house and mine at a pressure of 11 kV, the cable consisting of copper conductor supplied by the Pirelli-General Cable Works Ltd., having a cross sectional area of .05 sq. in. This is carried at approximately 400 ft. spans by tubular steel poles, 41 ft. high. Pin type insulators are employed for the straight portions of the line, but at section and angle points, strain insulators are fitted. Where the line crosses the River Subarnarekha, steel-cored aluminium conductor of 0.1 sq. in. sectional area is employed and is carried on two 75 ft. steel towers, each of which is supported by a 45 ft. steel anchor tower, thus forming three spans each of approximately 1,000 ft.

At each end of the line a 700 kVA oil-immersed self-cooled core type transformer is installed. One of these steps up the 420-volt supply to 11 kV for transmission to the mine shaft where it is transformed down by the second transformer to the original

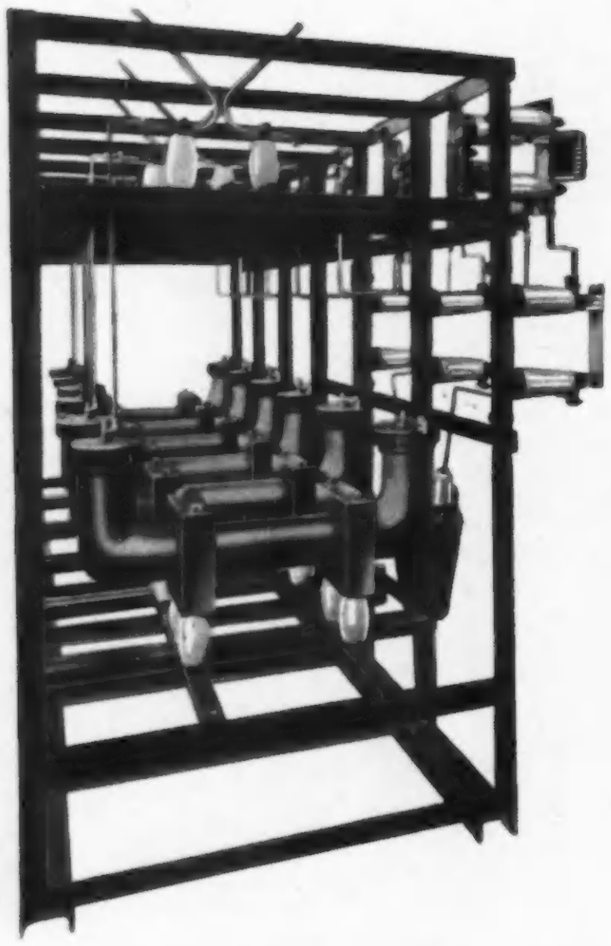


**Fig. 4.—Lightning protection equipment installed at each end of overhead line.**

voltage. For controlling the incoming supply from the overhead line to the mine, a steelplate cubicle is provided.

Protection of the line against lightning is afforded by a system of 11 kV lightning arrester gear installed indoors at each end of the line, and consisting of isolating links, choke coils, horn type arresters and liquid resistances mounted on angle iron frameworks (fig. 4). A 3-phase indoor type tension limiter, comprising 23 spark gap units (*i.e.*, six in each phase and five to earth), mounted in a suitable cubicle, provides additional protection by limiting the dynamic current which may follow a lightning discharge.

## MINE EQUIPMENT.

At the mine the ore is hauled to the surface up a two-compartment shaft (fig. 5) inclined at about 38° in 3-ton skips by the double drum electric winding engine illustrated in fig. 6. The driving motor of the winder is rated at 110 h.p., 730 r.p.m. and is of the protected slipring type. A drum type controller, operating in conjunction with continuously rated resistances, is employed for controlling the speed of the haulage motor, the stator of which is controlled by a pedestal type oil circuit breaker.

The mine headgear which continues the inclination of the shaft to a height of 73ft. 9ins. above ground level is of structural steel and supports a steelplate ore bin of 150 tons capacity. As the skips reach the top of the headgear they discharge their contents into this bin. From here the ore is discharged over a grizzley screen with 2in. spacings, the oversize passing to a jaw crusher set to 2in., while the undersize of the grizzley, together with the product of the jaw crusher, pass to a shaking screen with $\frac{5}{8}$in. perforations. The oversize of this screen passes to a 4ft. cone crusher, the product of which, reduced to $\frac{1}{2}$in. is taken together with the undersize of the shaking screen by an inclined belt conveyor which raises the whole to the top of a series of ore bins and distributes it by means of a tripper into the different compartments. From these bins the aerial ropeway receives the ore and conveys it to the concentration plant at Moubhandar.

A standby to the cone crusher is provided in a set of 42in. by 20in. crushing rolls, placed alongside the cone crusher. In cases of emergency the stream of ore may be diverted to the crushing rolls, thus ensuring continuous and uninterrupted operation.

Next to the headgear and crushing plant are the compressor house and machine shop. Two reciprocating air compressors are installed in the machine shop, fig. 7, each being driven by a 205 h.p. 324 r.p.m. 3-phase motor. These compressors are of 1,000 cu. ft. capacity and deliver air at 80 lbs. per sq. in. through 8in. pipes to the rock drills in the mine.

**Fig. 5.—Headgear at shaft head, showing belt conveyor to storage bins.**

The machine shop equipment includes lathes, drilling machines and other plant for repair work, all of which are driven by 3-phase slipring motors.

CONCENTRATING PLANT.

The concentration plant is capable of dealing with 400 tons of ore per day of 24 hours. The ore arriving by aerial ropeway from the mine, fig. 8, is delivered into a steel bin of 1,000 tons capacity, the bottom of which is raised 17ft. 6ins. above the ground. The ore, which is already crushed to ½in. at the mine, is discharged through openings in the bottom of the bin on to apron feeders, or short belt conveyors, and these convey it to chutes which deliver it into the feed boxes of two 7ft. by 30in. ball mills. Two Dorr Duplex Classifiers are placed beside the ball mills and operate in closed circuit with them.

The preparation of the ore for flotation includes its reduction to pass a 200-mesh screen. The discharge of the ball mill passes into the classifier which roughly separates the minus from the plus in size, returning the oversize to the ball mill for regrinding. The overflow, or finished material, from the classifiers passes to a sump from which it is raised by a centrifugal pump to two steady-head tanks serving the flotation machines.

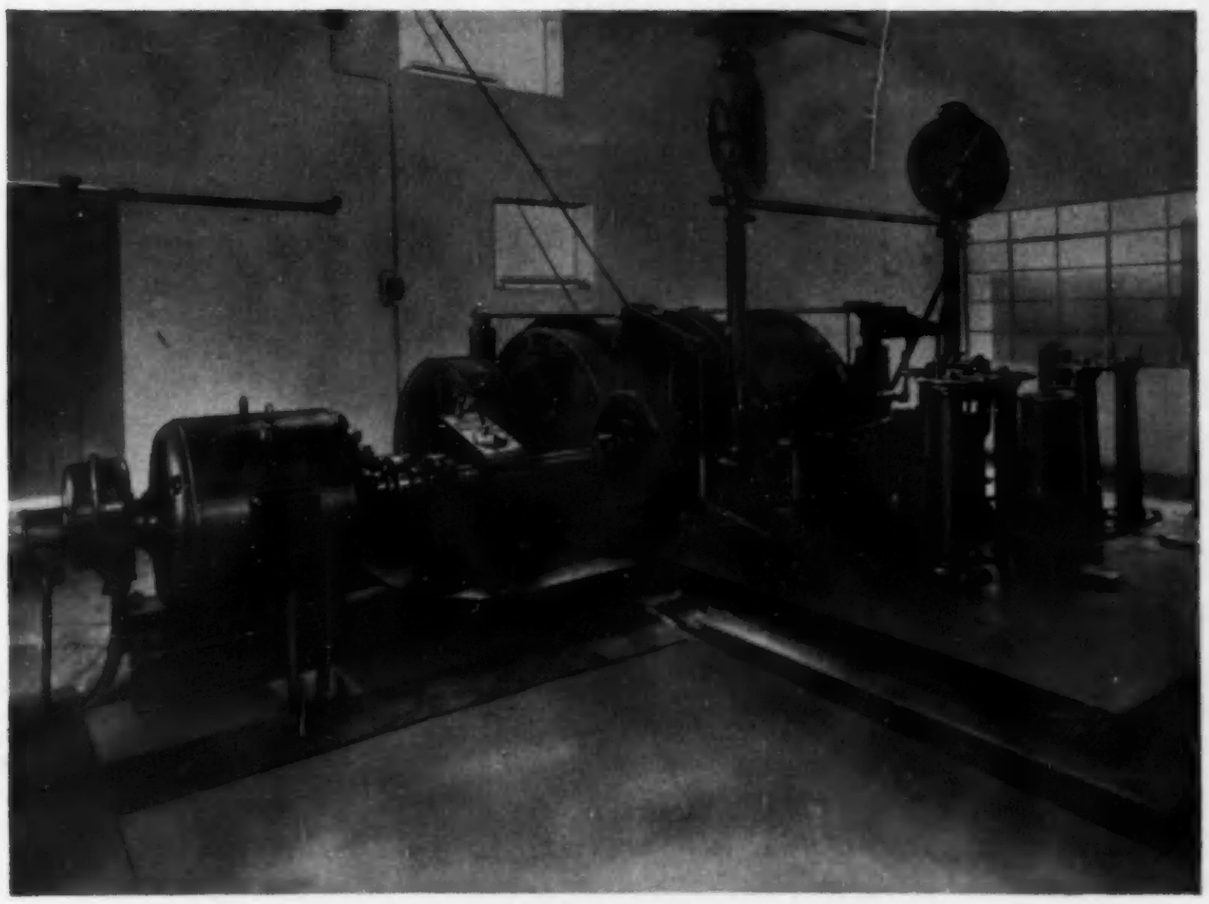


Fig. 6.—110 h.p. Electric winder at the mine.

These froth flotation machines, two of which are installed, are of the minerals separation sub-aeration type, each consisting of ten cells with frothing beaters, gear driven at 278.5 r.p.m. The pulp which is fed to the flotation machines consists of finely divided ore suspended in water. In order to produce the necessary frothing, a mixture of pine oil, xanthate and lime is added to the ore and water, in the proportion of 0·118 lbs. of pine oil and xanthate plus 2 lbs. of lime per ton of ore.

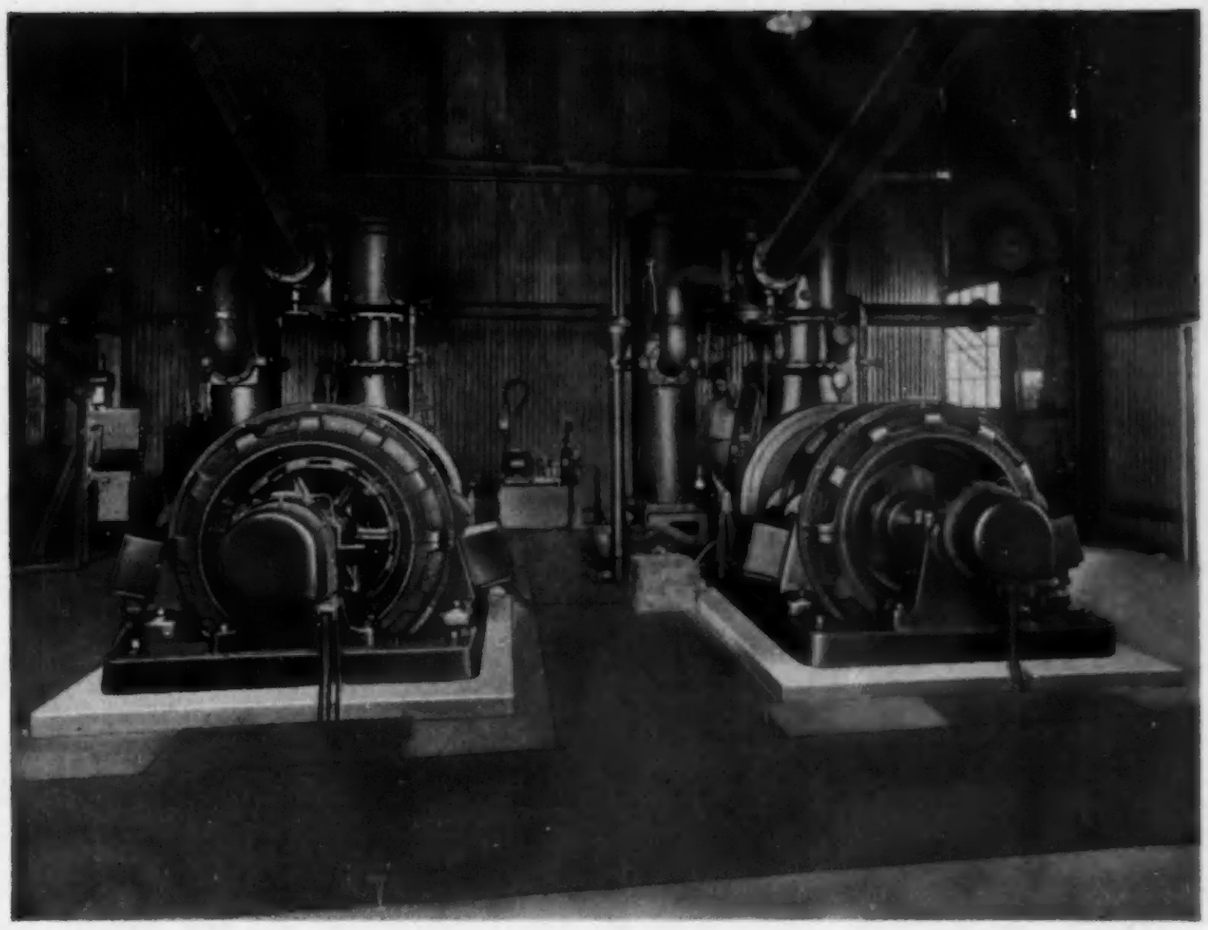


Fig. 7.—Two 200 h.p., 324 r.p.m. motors driving reciprocating air compressors.

The agitation of the ore pulp containing this small amount of oils, and the injection of air from a Roots type blower into the pulp, cause air bubbles to rise which carry with them the particles of copper-bearing mineral. As these bubbles reach the surface they collect as a mineralized froth which is drawn off as a concentrate, the sediment being discharged to waste. The concentrate, which forms about one tenth of the original ore and contains 96 per cent. of the copper, is de-watered in a Dorr Thickener. After this process, the concentrate is passed through two Oliver de-watering filters, and the remaining moisture is then evaporated by two Lowden type dryers. These dryers are of brickwork and consist of a hearth 6ft. wide by 30ft. long, over which the ore is distributed and continuously raked from feed end to discharge end by mechanical rabbles. The heat is derived from a fire-box beneath the hearth, the gases passing along return flues to a chimney.

Eight 3-phase slipring motors are employed for driving this plant, namely, two 120 h.p., 725 r.p.m. pipe-ventilated motors driving the two ball

mills through a silent chain drive transmission; two 60 h.p., 950 r.p.m. motors driving the two series of flotation cells and the pumps by belt and countershafting; three 25 h.p., 950 r.p.m. motors driving by belt and countershafting the apron feeders, centrifugal pump, air compressor and vacuum pumps, and one 25 h.p., 1,400 r.p.m. drip proof motor driving by belt and countershafting the sand pumps and steadyhead agitating tanks. Each motor is provided with the necessary control gear in the form of a pedestal type oil-immersed switch fitted with overload trips, no-volt release, and interlocked with an oil-immersed rotor starter.

**Fig. 8.—Steel ore receiving bins at the Reduction Works.**

### SMELTING PLANT.

From the dryers the concentrated ore, carrying 30 per cent. copper, is conveyed in one-ton side-tipping trucks to a platform elevator, supplied by The Express Lift Co., Ltd., which raises the trucks to the top of a series of bedding bins from which ore, fluxes and fuel are drawn for charging to the smelting furnaces.

The smelting furnace, which is of the reverberatory type having an average hearth area of 15ft. 6ins. by 34ft., is composed of brickwork, reinforced on the outside with steel buck-stays and binders. It receives the ore through a series of hoppers and chutes situated along each side of the furnace hearth, the object of this system of feeding being to protect the walls against the erosive action of the molten matte and slag. The furnace is fired with pulverized fuel through three feed nozzles projecting through one end of the furnace.

The slag is discharged at the end of the furnace opposite to the firing burners into slag cars drawn by 20 h.p. paraffin rail tractors, which convey it to the slag dump. The matte is discharged at the same end of the furnace as the slag but from one side of the hearth and at a lower level. It can thus be drawn off into 5-ton matte ladles within reach of the four-motor electric travelling crane which spans the width of the converter house. In the matte produced, the concentration of the copper is increased to about 39.6 per cent., the remainder consisting chiefly of iron and sulphur.

### CONVERTER PLANT.

Two converter stands of the vertical, or "Great Falls," type are installed, 8ft. in diameter and basic lined with magnesite. These are illustrated in fig. 9.

Each coverter is tilted by means of a 15 h.p. motor, which, due to the worm gear drive employed, and the provision of solenoid brakes, is capable of being controlled from a very low creeping speed to its maximum of 710 r.p.m. by means of a drum type controller provided with continuously rated resistances.

Each converter is fitted with fourteen 1 in. bore tuyeres, through which an air blast at 12 lbs. per sq. in. is distributed from a wind-box extending round the outside radius of the converter shell occupied by the tuyeres, the air blast being turned on as soon as the matte is poured into the converter. Briefly, the process of converting consists in oxidizing and slagging the iron sulphide ($FeS$) by forcing air through the molten matte—in effect, Bessemerizing.

For fluxing the sulphide, silica is necessary, and this is provided by periodically adding to the charge quartz as high in free silica ($SiO_2$) as possible, though if it contains any copper the process becomes more economical. The slag forms on the surface of the metal and is drawn off by tilting the converter until only "blister" copper remains, consisting of about 99 per cent. copper. This is transferred in the molten state by ladle and crane (fig. 10) to the

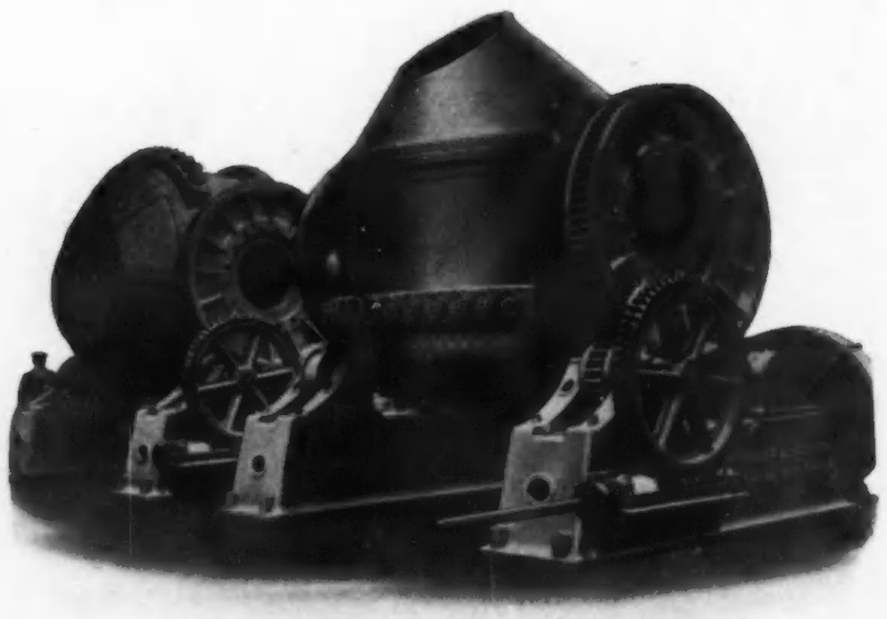


**Fig. 9.—Converters of the "Great Falls" type.**

refining furnace where the remaining impurities are removed. The slag from the converter contains sufficient copper to render desirable its retreatment for the recovery of its copper content. It is therefore allowed to cool and is then broken up and returned to the smelting furnace.

The equipment of the converter plant includes a turbo-blower having a capacity of 3,000 cu. ft. per min. at a maximum pressure of 15 lbs. per sq. in. This is driven by a 250 h.p. protected type slipring motor running at 1,450 r.p.m. There are also three 60 cu. ft. slag cars, four 34 cu. ft. cast steel matte ladles with lifting bales and the four-motor electric crane previously mentioned. Steel hoods are also provided for collecting the fumes and gases from the converters, while a balloon-section flue conveys the gases to dust chambers.

For crushing the fluxes required by the smelting furnace and the converters, a separate crushing plant is installed, comprising a 12in. by 8in. Dodge crusher, one set of 16in. by 10in. crushing rolls, a 16in. portable belt conveyor, one 30in. dia. by 8ft. long revolving screen with 5/16 in. perforations, and a 35 h.p. 720 r.p.m. pipe ventilated motor for driving the plant.

REFINING.

The blister copper discharged from the converter is run into ladles and conveyed by the overhead crane to a reverberatory refining furnace (fig. 11). This furnace is constructed of brickwork, special refractory bricks being used for lining the hearth, side walls and roof inside the furnace. The furnace is encased on the outside with steel buck-stays and binders, and is fired from one end with pulverized coal. Openings are provided for skimming off impurities in the form of slag and for drawing off the refined metal into ingot moulds. The refined product consists of about 99.9 per cent. copper and is of sufficient purity to be used for some purposes for which only electrolytic copper could hitherto be employed. The slag, being rich in copper, is allowed to cool, broken up and, with the converter slag, returned to the smelting furnace.

Fig. 11.—Copper refining furnace and firing end of reverberatory matting furnace.

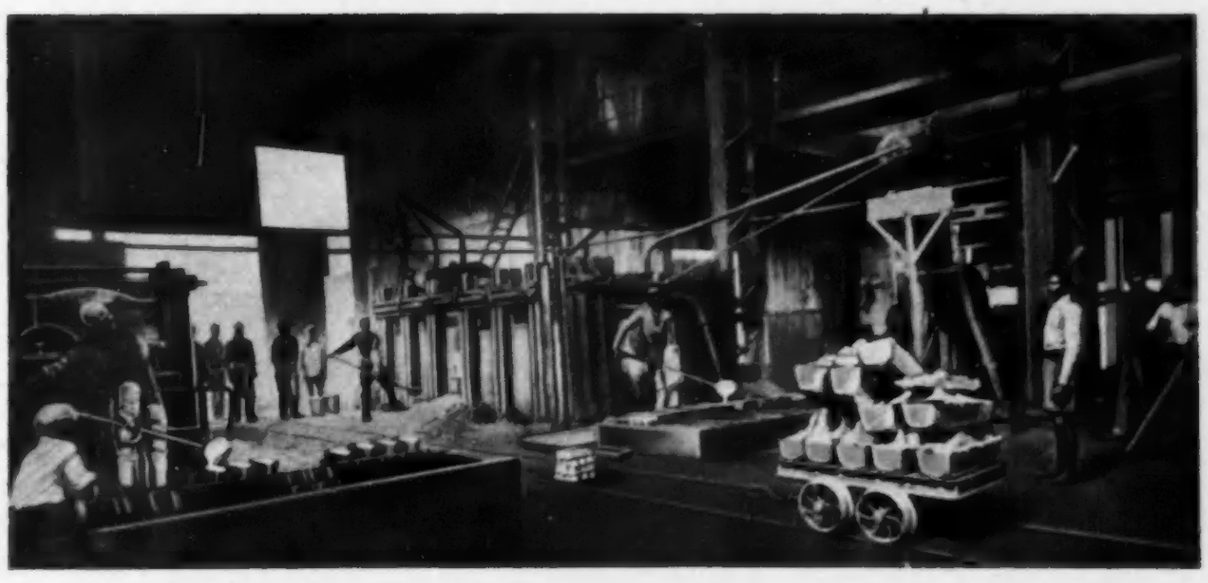


Fig. 10.—Casting copper ready for refining.

CONCLUSION.

It will be appreciated that in establishing a pioneer metallurgical works of such magnitude and in organising its economical commercial operation, numerous difficulties were encountered. Not the least of these was the transport problem. Although the transport of the machinery for the reduction works and power house, both of which are situated close to the railway, caused comparatively little trouble, the heavy machinery for the mine, over five miles away, had to be hauled in native bullock wagons over tortuous roads and bullock tracks, through jungle and across the river at an improvised ford.

The chief problem, however, lay in training the native labour to perform the various duties required of them in the reduction works, particularly in the smelting and converting departments, where the artificial heat added to the high climatic temperature, renders such work very exacting. The natives of this part of India, though intelligent and tractable enough, are inherently of poor physique and, due to their simple dietary (chiefly of rice), they possess little stamina. Their simple mode of life, in which their necessities are few and easily acquired, is also subversive of any particular zeal in the pursuit of a strenuous occupation. It is therefore greatly

to the credit of the management that all departments of the works were functioning smoothly and efficiently within a very short time of the installation of the plant.

The copper produced is of exceptional purity and finds a ready market in India. As practically all the copper previously used in the country was imported and bore a duty of 15 per cent. (recently increased to 20 per cent) the company started with a substantial advantage and even at the very low market price of copper now prevailing, they are able to make a profit which in the open market would be impossible to obtain. The copper industry of India thus protected has not only been enabled to establish itself, but receives encouragement under which it is likely to progress to the full extent of the resources of its mines and the demands of its industrial requirements.

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# Electric Shunting Locomotives for China.

THE electric locomotive illustrated below is one of two supplied to the Chinese Engineering and Mining Co. (Kailan Mining Administration) in connection with the electrification of the company's Chinwangtao lines. Both locomotives are to be employed for shunting work and for the haulage of coal from the mines to the wharves.

**One of the two 500 h.p. electric shunting locomotives supplied to the Chinese Engineering and Mining Co.**

Each locomotive is mounted on two motor bogies, the locomotive body comprising a central driving cab and two end structures in which the control and auxiliary apparatus are accommodated. Power is supplied from an overhead line at 1,000 volts D.C., three current collectors being mounted on the roof of the cab. One of these is a spring-operated pantograph, the other two being bow collectors intended for use at the wharves. The driving cab contains the controller, circuit breaker set and trip switch, control switch and the necessary heating and lighting switches. The usual meters and brake pressure gauges are also fitted.

Two 132 h.p. axle-hung, self-ventilated motors, permanently connected, in series are mounted in each bogie and are geared direct to the axles through spur gearing. Each motor is insulated for 1,000 volts to earth, the four motors of each locomotive exerting a tractive effort of approximately 4,850 lbs. on the one hour rating, and driving the locomotive at a speed of approximately 8½ miles per hour.

The controllers are of the manually operated cam type, the main resistances being housed in one of the end structures, access to which is obtained through the side doors seen in the illustration and also from the top. The other container accommodates the main circuit breaker, auxiliary control gear and the air compressor for the automatic air brakes.

The sub-station gear and overhead line for the 1,000 volt supply, were supplied by The General Electric Co., Ltd., and the locomotives jointly by the G.E.C. and Les Ateliers de Construction Oerlikon.

# Industrial Electric Heating.

## PART II.—THE HEAT TREATMENT OF STEEL.

By VERDON O. CUTTS.
Industrial Heating Dept. of The General Electric Co., Ltd.

BEFORE proceeding to discuss the practical applications of electrical heating to steel, it is necessary to explain that resistance furnaces and equipment may be divided into two main groups. These are the direct and indirect types.

### DIRECT TYPE FURNACES.

There are two direct methods of applying electrically produced heat by resistance, both of which are used in industry. In one method an electric current is passed between terminals fixed to the actual material to be heated. This is an autogenous process which is restricted in its application to the heating of materials which are electrical conductors. It will be apparent that uniformity of heating by this means can only be obtained if the material being heated is of uniform cross sectional area and resistance. This method has been applied to the heating of metallic wires and tubes and also to columns of material in granular form which are usually mixed with a carbonaceous material. Considerable success has attended the application of this principle to the finish annealing of condenser tubes, which is a comparatively low temperature process.

There are many serious practical difficulties which prevent its more general use. When handling tubes of identical length and area and working at low temperatures, a positive electrical connection is readily made. Even under these conditions the success of the process depends upon a uniformity of structure which can only be relied upon in a finished high grade product. Substantial variations in the physical structure of the material being heated (due to unequal mechanical working) cause marked variations in electrical resistance and consequently in the heating effect in one piece of material. Attempts to adapt this system to continuous operation have so far been frustrated by the difficulties encountered with fixed contact blocks.

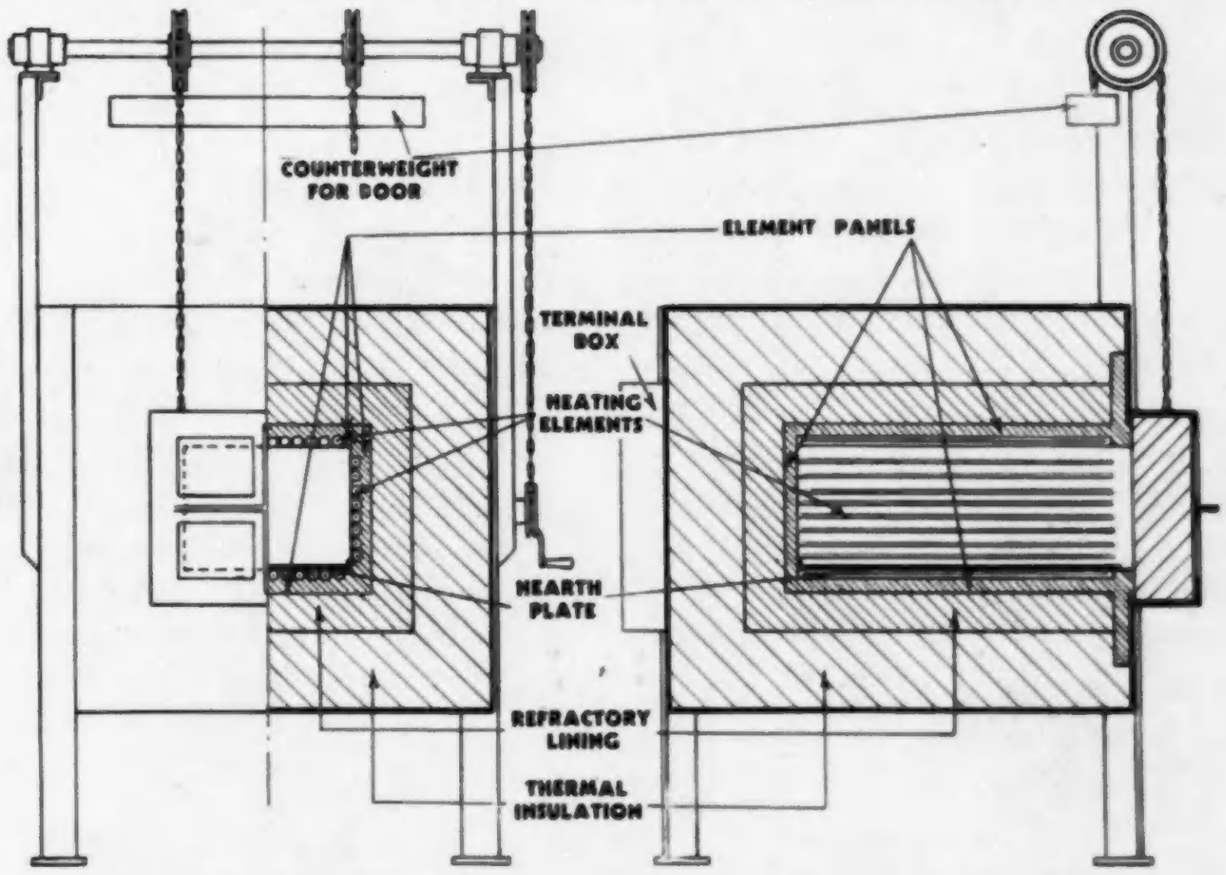


**Fig. 7.—Simple resistance type electric furnace with nickel-chromium heating elements.**

The other method of direct resistance heating is better known as induction heating. In this an electric current is induced in the material being heated by making it the secondary of a transformer. Such furnaces are classified as high, medium and low frequency installations according to the frequency of the circuit. Induction heating is employed on a considerable scale for the melting of metals and also, to a very limited extent, for the heating of metallic pieces of uniform cross section.

Although the two *direct* methods just described are strictly speaking of the resistance type, they are

not normally included in a general reference to resistance type furnaces. They are sufficiently distinct in their character and application to be referred to more precisely as of the direct-resistance and induction types.

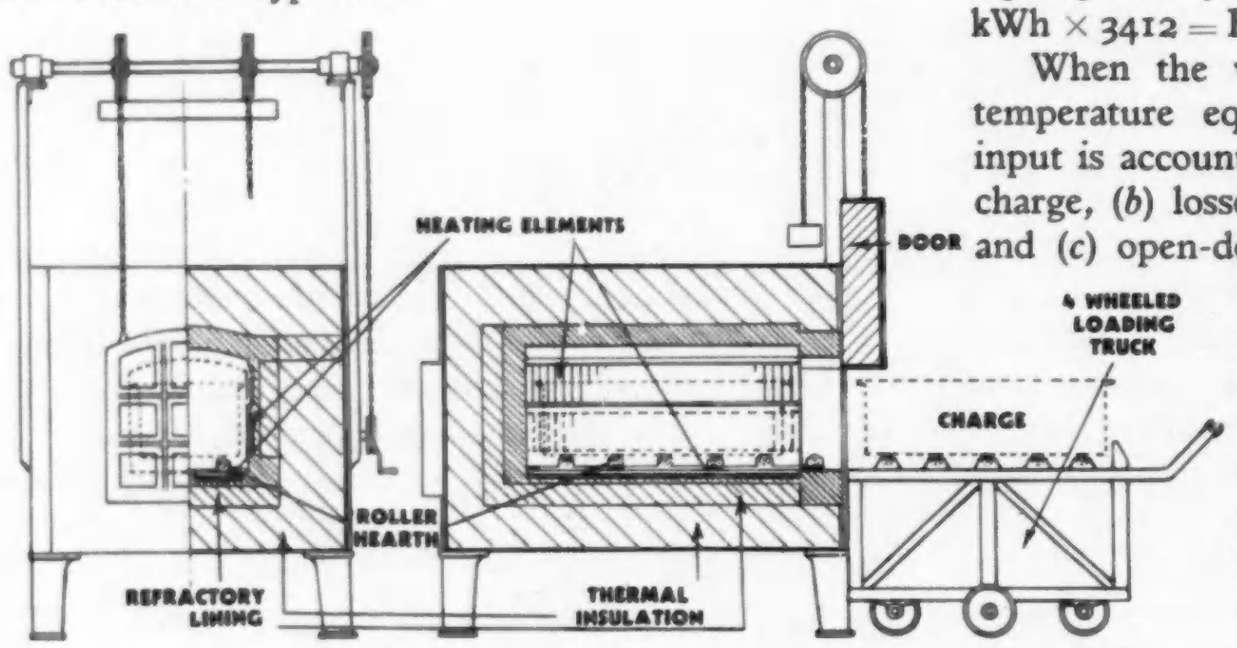


Fig. 8.—Electric furnace with nickel-chromium heating elements.

## INDIRECT TYPE FURNACES.

The general term "resistance type" is usually employed when referring to furnaces, ovens and equipment of the *indirect* type in which the heat is generated by the resistance of an extraneous material to the passage of an electric current. This is the class of furnace and electric heating equipment which is being dealt with in this series of articles.

Typical examples of resistance type electric furnaces are shown in figs. 7 to 13, their outstanding features being simplicity of design, wide range of application and ease of control. In each case these furnaces consist essentially of a chamber which is built of suitable refractory materials and surrounded by thermal insulation. Heating elements of different types are so disposed within the chamber as to ensure uniform heat distribution. In this type of furnace the generation of heat is not influenced by the character or shape of the material which forms the charge to be heated. The independent heating elements are of known electrical resistance and uniform section, thus permitting of a definite predetermined electrical input to the furnace chamber, and therefore of a corresponding definite heat input given by the equation :—

kWh $\times$ 3412 = B.Th. U. (delivered into the furnace).

When the walls of the furnace have reached temperature equilibrium, the whole of the heat input is accounted for by (*a*) heat absorption of the charge, (*b*) losses through the walls of the furnace, and (*c*) open-door losses. The losses through the furnace walls and doors being definitely calculable, the amount of heat available for raising the temperature of the charge is known. The fact that results can readily be calculated greatly assists in putting workshop practice on a precision basis. There are no unknown or variable quantities to be taken into consideration. In the development of electric furnaces of this type, adequate thermal insulation has not been overlooked.

## HEATING ELEMENTS.

Reference has already been made to heating elements of different types, but it should be explained that, while there are many metallic and non-metallic substances which are suitable for use as electric heating elements, the majority of industrial requirements are satisfied by three materials, each of which has its own field of application. These are (*a*) nickel-chromium alloy in the form or wire, rod or strip, (*b*) granular carbon contained, or confined, in suitable high resistance troughs, and (*c*) re-fused silicon carbide in the form of rods. They are here mentioned in the order of their normal temperature limitations so far as general industrial applications are concerned. By far the most commonly used of these materials are the nickel chromium alloys which cover the range up to 1,000° C.

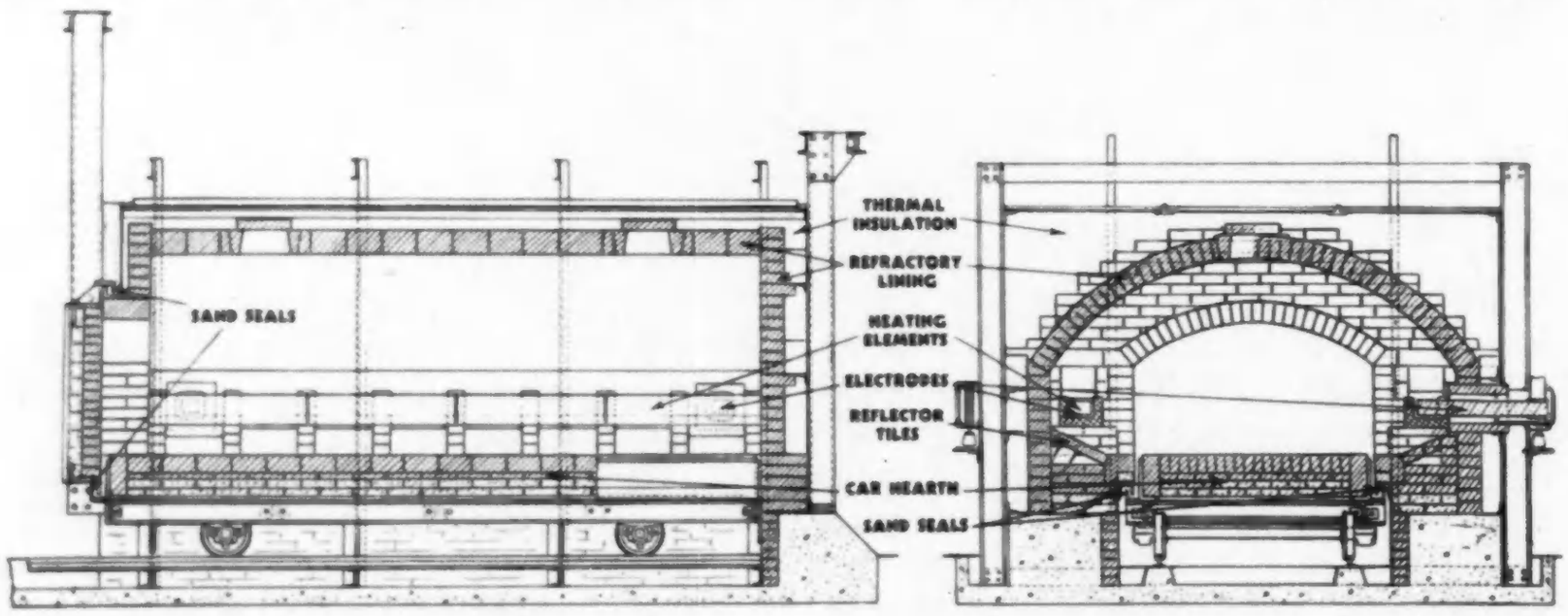


Fig. 9.—Electric furnace of the resistance-radiation type employing heating elements of granular carbon.

### PRACTICAL APPLICATIONS.

Turning to a consideration of the various practical applications of resistance type electric furnaces, such a diversity of uses is immediately apparent as to necessitate the adoption of some method of grouping or classification. It will therefore be convenient to begin with the heat-treatments of steel which come within the permissible temperature range of normal furnaces in which nickel-chromium heating elements are used.

### HEAT-TREATMENT OF STEEL.

Probably no branch of metallurgy has advanced so rapidly as the heat-treatment of steel. Whereas but a short time ago it was a mystery practised by the few in a secretive way—and even then in an approximate and crude rule-of-thumb manner—now it is a precise science of almost universal application. Generally speaking, the heat treatment of steel comprises various methods or combinations of heating and cooling with a view to producing, establishing, or rendering permanent, a desired structure and physical condition. In order fully to understand all that is implied by this (and especially by the term "structure") a knowledge of metallurgy and metallography is necessary. These are subjects which, however, are outside the scope of this series of articles.

The composition of the steel under treatment (especially its carbon content) not only governs the extent to which heat-treatment will affect its mechanical properties by regulating its constituents and grain size, but also the temperatures at which changes will occur. Heat-treatment of steel usually implies (*a*) heating to a pre-determined temperature (generally just above the critical point), (*b*) quenching in either oil or water, (*c*) re-heating to some lower temperature to secure whatever physical properties are desired and (*d*) cooling slowly.

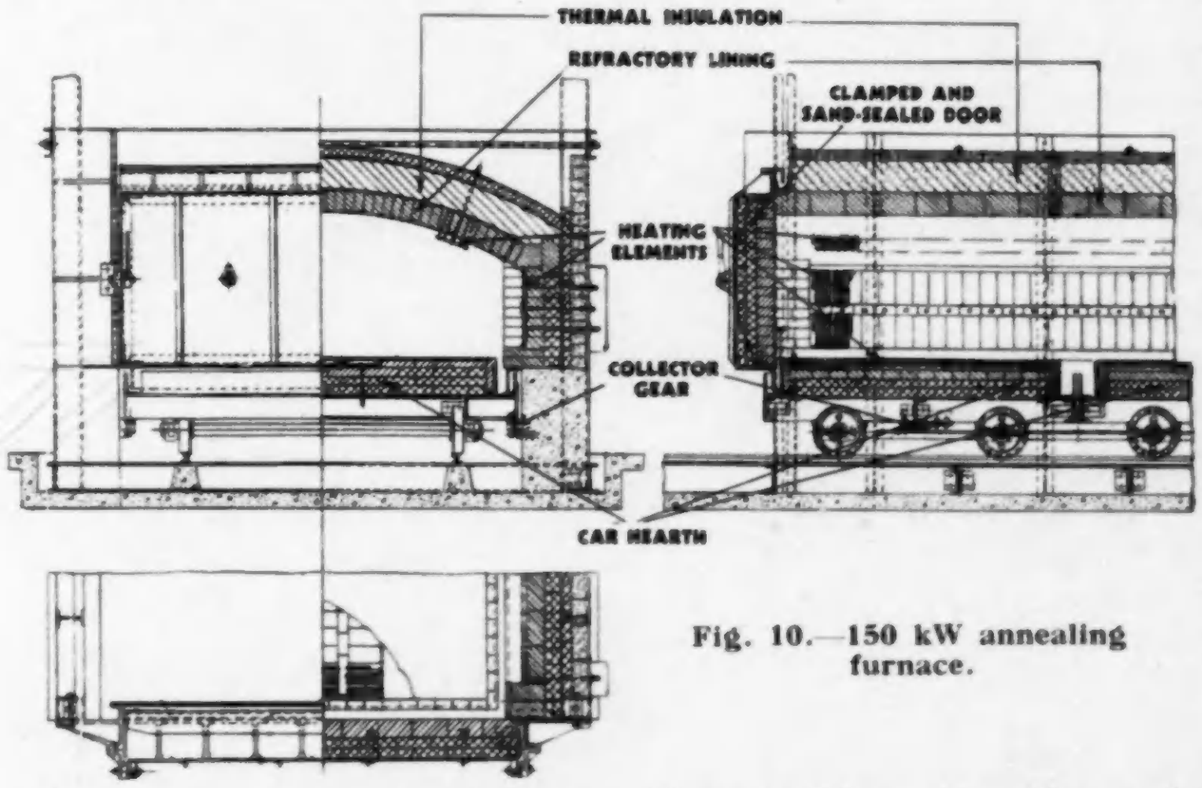


Fig. 10.—150 kW annealing furnace.

The electric furnace asserts itself for this work because it is vital that the temperature to which steel is heated should be determined with the greatest possible precision that is consistent with works practice and shop conditions. Failing this,

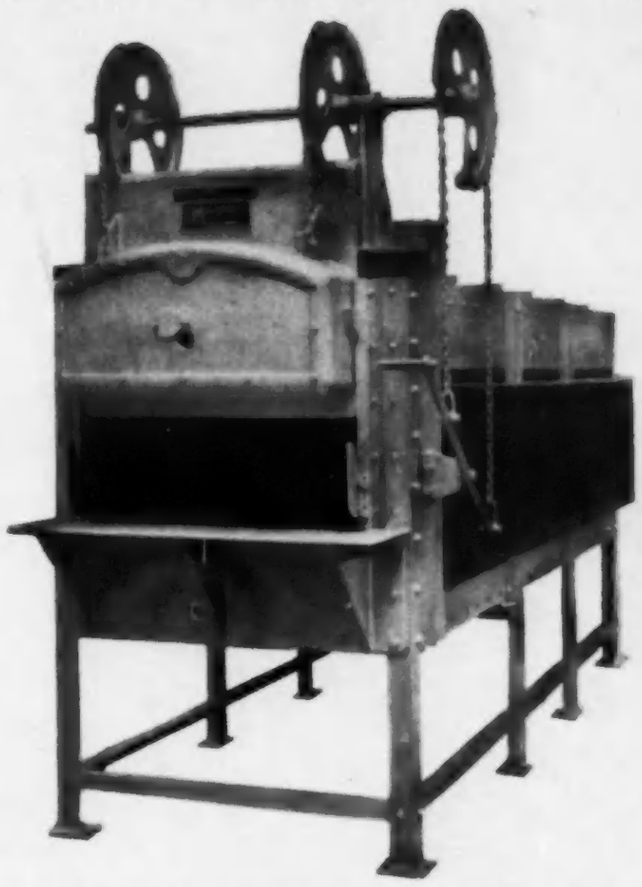

Fig. 11.—High temperature electric furnace with silicon carbide heating elements.

an otherwise good steel may be completely ruined for the purpose for which it is intended. Especially is this true of alloy steels and higher carbon steels.

The importance of the second heating, or final re-heating, temperature and its influence on the ultimate physical properties of a steel may be illustrated by the fact that, if this is carried out at the lower permissible temperatures, it will ensure high elastic limits and low ductility, whereas higher re-heating temperatures give greater toughness. It is therefore imperative, if the desired results are to be obtained, that this heating should be accomplished with that precision which is characteristic of the electric furnace.

### ANNEALING OF STEEL.

The objects of annealing are to relieve internal stresses and strains, to soften the steel and to refine its grain, thus increasing its ductility. Generally speaking, the higher the carbon content of the steel, the lower is its critical point and, consequently, its annealing temperature is lower. Certain it is that there is a correct annealing temperature for each steel and the best results are obtained by annealing in an electric furnace. With fuel-fired furnaces there is considerable danger of exceeding the correct temperature in some parts of the charge during the soaking period. The precise adjustment and uniform distribution of temperature

obtained in electric furnaces when annealing steel are all illustrated in figs. 5 and 6, pages 113 and 114 in Vol. 1, No. 3, of the *G.E.C. Journal*.

There are numerous annealing operations for which the electric furnace offers special advantages. The bright annealing of metals, although an annealing process, will be dealt with in a subsequent article because of the special nature of the furnaces which have been developed for this particular process. Electric furnaces are being employed for the short-cycle annealing of malleable castings, and also for the annealing of manganese steel castings.

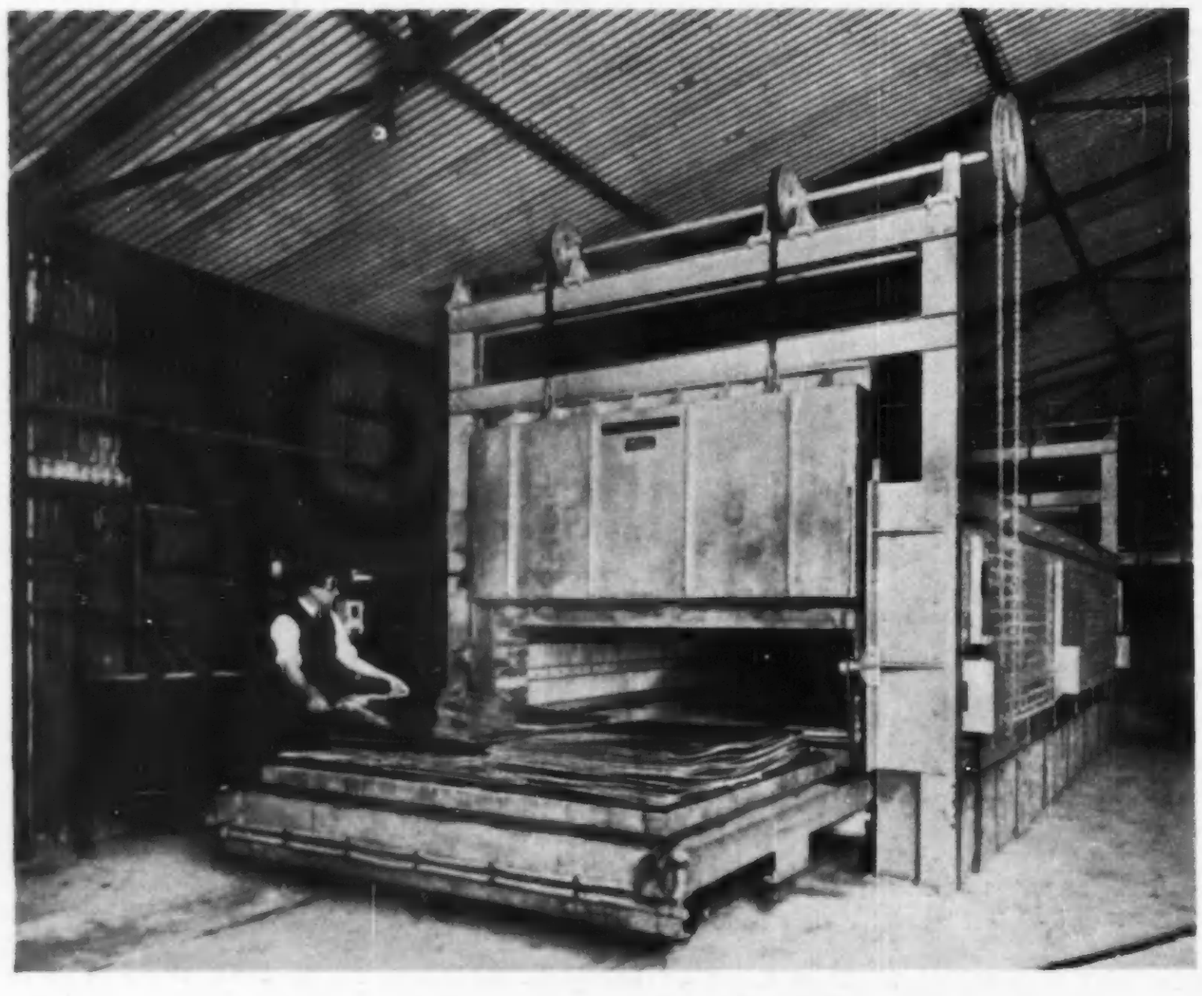

**Fig. 12.—150 kW annealing furnace erected at the Dalgarrog Works of the Aluminium Corporation, Ltd.**

### HARDENING AND TEMPERING OF STEEL.

Heating for hardening is very similar to heating for annealing; the essential difference in the treatment being in the rate and method of cooling. For hardening purposes rapid cooling is essential. This is usually achieved by quenching in water or oil. The heating must be slow, uniform and thorough, and the cooling must be effected as uniformly as possible.

Tempering effects a compromise between hardness and toughness. Hardened steel may be so brittle and in such a state of strain as to be useless for the purpose for which it is intended. This condition is relieved and toughness imparted at the expense of a slight decrease in hardness by careful heating and well controlled cooling.

Uniform heating and cooling are essential. The electric furnace may be depended upon for the uniform heating. Electrically heated lead baths also prove ideal for the tempering of steel pieces of suitable size and shape and will be described in a subsequent article dealing with metal melting pots. Electric salt bath furnaces are very popular in many works for this purpose; they ensure uniformity of heating, gradual heating and the elimination of oxidation owing to the thin film of salt which adheres to the steel as it is withdrawn from the bath.

### CASE-HARDENING OF STEEL.

Case-hardening, or carburising, is a cementation process which produces a hard wearing surface while retaining a tough core. The surface of the piece is impregnated with added carbon. Pieces to be heated are packed in boxes in which they are surrounded by, and in intimate contact with, a carbonaceous substance which is usually referred to as a case-hardening compound or cement. The box and its contents are heated to, say, 870°C. to 950°C. Subsequent heat treatment is generally necessary. This varies with the steel itself, the purpose for which it is intended and the temperature at which the case-hardening has been carried out. Both the case-hardening and the subsequent re-heating demand precise temperature control. Electric furnaces may be relied upon for greater consistency in this work than is possible with fuel-fired furnaces. Both box type and continuous conveyor hearth type electric furnaces are extensively used for this purpose.

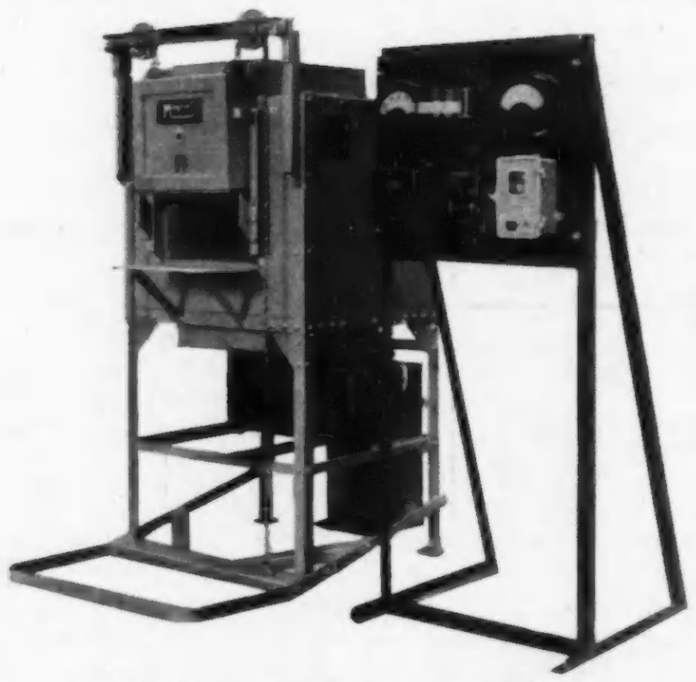

**Fig. 13.—Standard high temperature furnace for tool hardening.**